Knowledge and Technology Transfer from HEP

Photo: CNAO treatment room

Manuela Cirilli
CERN Knowledge Transfer Group

MEMORIAL SYMPOSIUM 2021
BRUNO TOUSCHEK 100 years

1951 2021 infn
70 ANNI DI RICERCA PER TRACCIARE IL FUTURO

CERN Knowledge Transfer
Accelerating innovation


WHERE THE
WEB
WAS BORN

ASSEMBLÉE NATIONALE

SÉNAT

Briefing n° 12

Large particle accelerators

February 2019

Ring segment of a particle accelerator
© fotonat67 / Adobe Stock

Summary

- Particle accelerators, like other kinds of "very l
(VLRI), make it possible to manage cutting-e
strategic issues: acquiring knowledge, enhan
preparing for technological breakthroughs, sci
- CERN, the European particle physics labora
biggest circular particle accelerator in the wor
the highest energies produced to date.
- A decision by the Japanese government is ex
accelerator project, the ILC, proposed sin
scientific community.
- *Thinking on the future European strategy for particle physics began in 2018 and should be presented in spring 2020. If the Japanese government confirms its interest in ILC, this European strategy must take account of this fact: a possible contribution from Europe, and particularly France, must be assessed in terms of scientific return, cost and industrial benefits.*

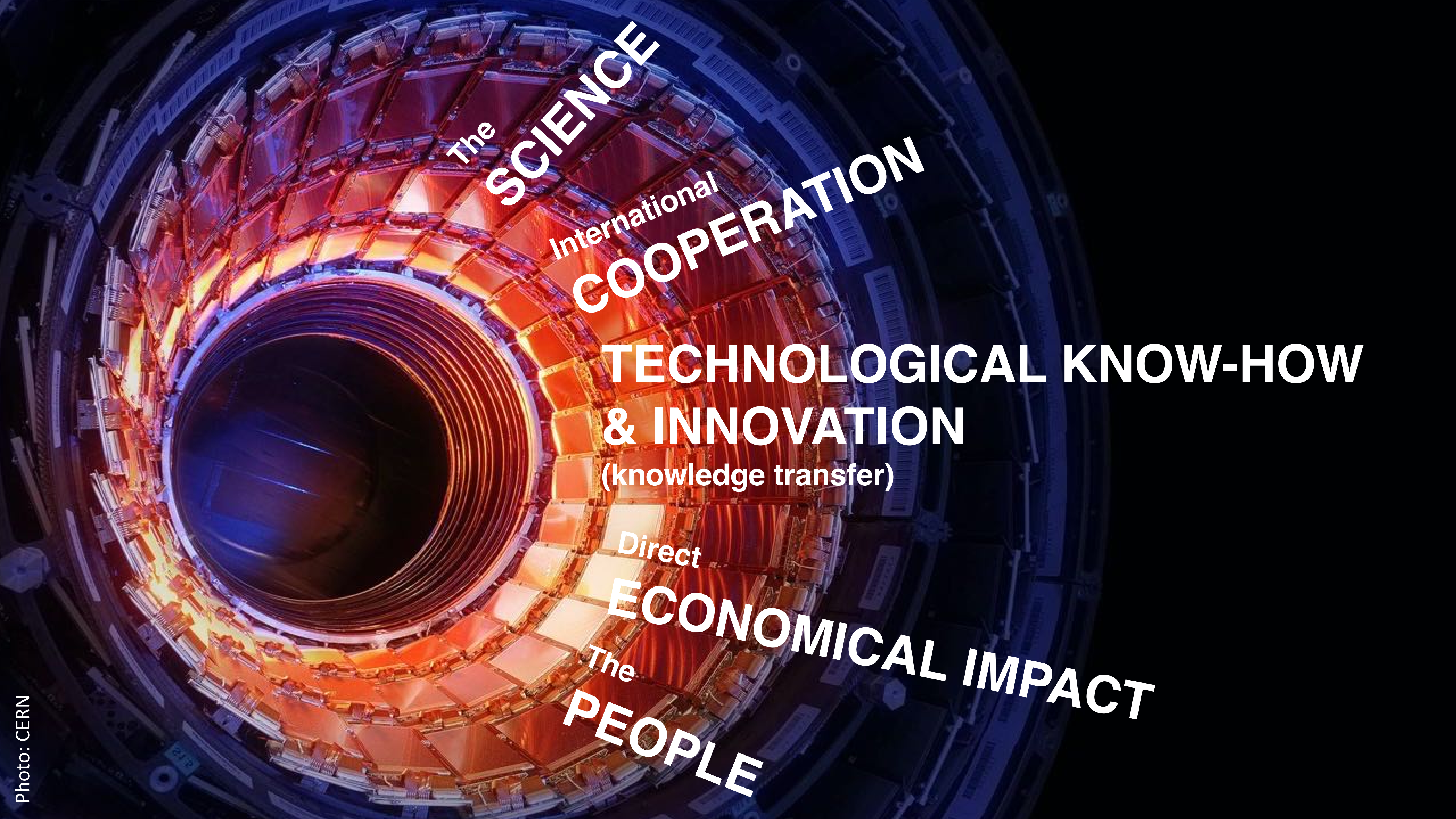
Mr. Cédric Villani, MP (National Assembly), First Vice-Chairman

CERN has also had a very strong societal impact via **the creation of the *World Wide Web* (WWW)** in 1989[21] under the leadership of Tim Berners-Lee and his collaborator Roger Cailliau. It was originally a response to researchers' need to exchange a high volume of data simply and instantaneously for

TECHNOLOGICAL KNOW-HOW & INNOVATION

(knowledge transfer)

Photo: CERN


The SCIENCE
International COOPERATION
TECHNOLOGICAL KNOW-HOW & INNOVATION
(knowledge transfer)
Direct ECONOMICAL IMPACT
The PEOPLE
Photo: CERN

SCOAP³ Sponsoring Consortium for Open Access Publishing in Particle Physics

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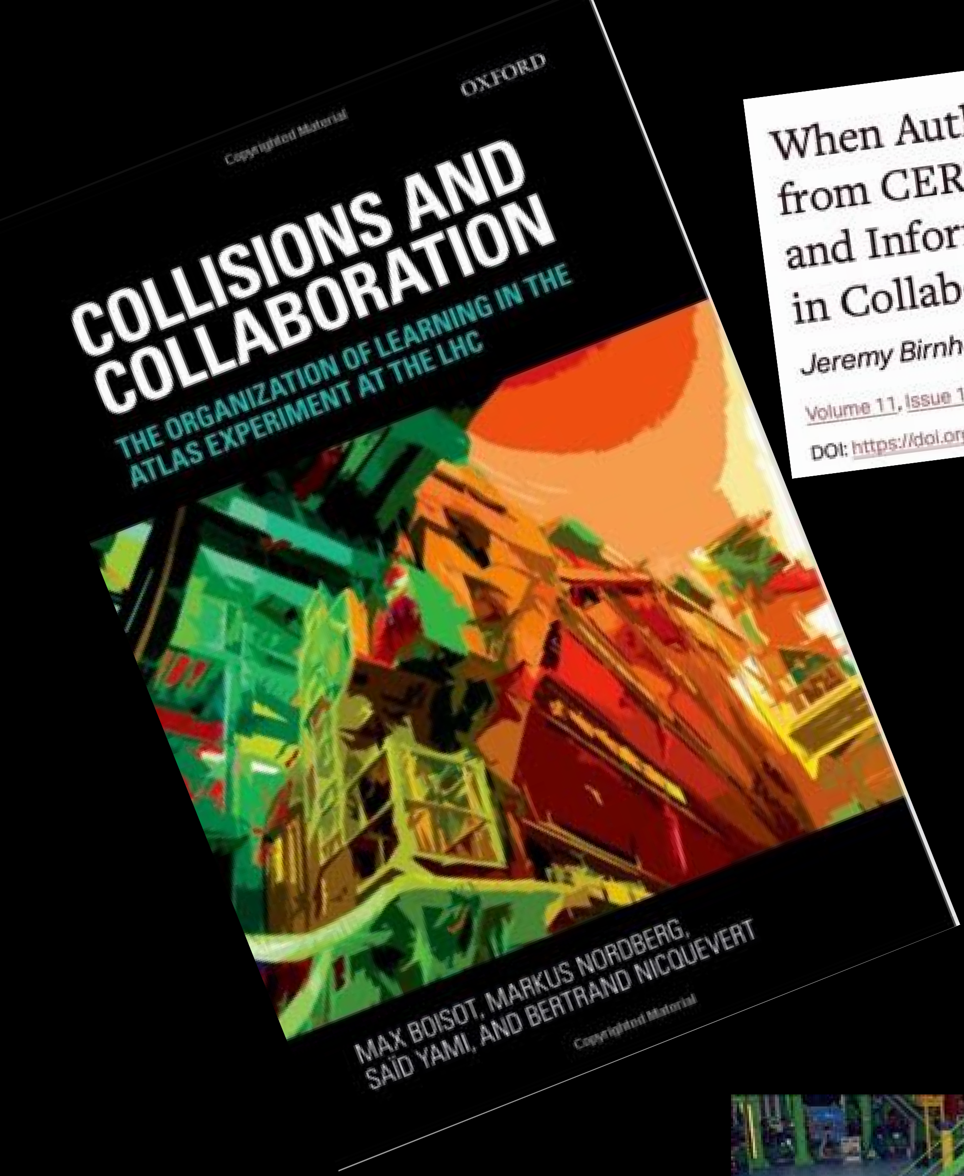
Articles funded by SCOAP³:

38	604	7 016	46 704
yesterday	last 30 days	in 2021	since 2014



When Authorship Isn't Enough: Lessons from CERN on the Implications of Formal and Informal Credit Attribution Mechanisms in Collaborative Research

Jeremy Birnholtz

Volume 11, Issue 1, Winter 2008

DOI: https://doi.org/10.3998/3336451.0011.105

CONCEPTUAL ANALYSIS article

Front. Res. Metr. Anal., 13 January 2021 | https://doi.org/10.3389/frma.2020.592819

Collaborative Processes in Science and Literature: an In-Depth Look at the Cases of CERN and SIC

Emilia Leogrande[1]* and Renato Nicassio[2]*

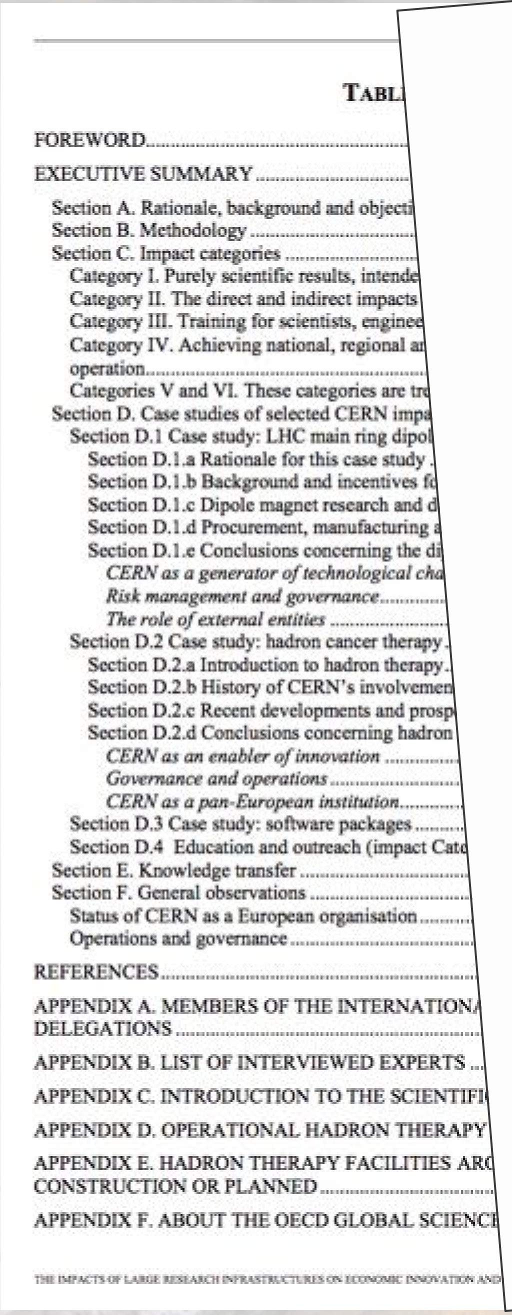
[1]European Organization for Nuclear Research (CERN), Geneva, Switzerland

[2]Independent Researcher, Bari, Italy

The European Network for Light Ion Hadron Therapy (ENLIGHT) was established to co-ordinate European efforts in using ion beams for radiation therapy and to catalyse collaboration and co-operation among the different disciplines involved. ENLIGHT had its inaugural meeting in February 2002 at CERN and was funded by the European Commission for its first 3 years.

http://cern.ch/enlight

ENLIGHT

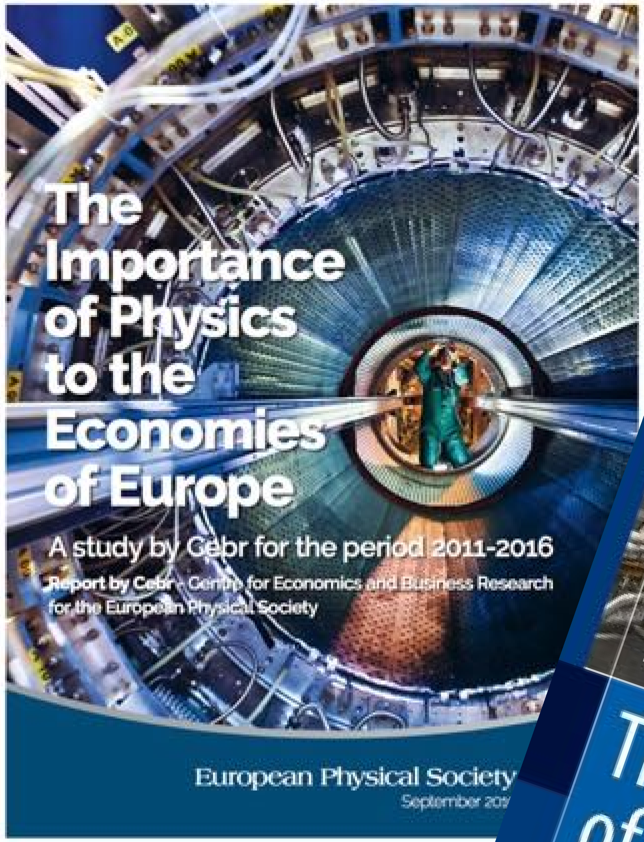


TABL

The Impacts of Large Research Infrastructures on Economic Innovation and on Society:

Case Studies at CERN

OECD



Cost-Benefit Analysis of the Large Hadron Collider to 2025 and beyond

Massimo Florio[1], Stefano Forte[2], and Emanuela Sirtori[3]

[1] *Dipartimento di Economia, Management e Metodi Quantitativi, Università di Milano , via Conservatorio 7, I-20122 Milano, Italy*
[2] *TIF Lab, Dipartimento di Fisica, Università di Milano and INFN, Sezione di Milano, Via Celoria 16, I-20133 Milano, Italy*
[5] *CSIL, Centre for Industrial Studies Corso Monforte 15, I-20122 Milano, Italy*

Abstract

Social cost-benefit analysis (CBA) of projects has been successfully applied in different fields such as transport, energy, health, education, and environment, including climate change. It is often argued that it is impossible to extend the CBA approach to the evaluation of the social impact of research infrastructures, because the final benefit to society of scientific discovery is generally unpredictable. Here, we propose a quantitative approach to this problem, we use it to design an empirically testable CBA model, and we apply it to the the Large Hadron Collider (LHC), the highest-energy accelerator in the world, currently operating at CERN. We show that the evaluation of benefits can be made quantitative by determining their value to users (scientists, early-stage researchers, firms, visitors) and non-users (the general public). Four classes of contributions to users are identified: knowledge output, human capital development, technological spillovers, and cultural effects. Benefits for non-users can be estimated, in analogy to public goods with no practical use (such as environment preservation), using willingness to pay. We determine the probability distribution of cost and benefits for the LHC since 1993 until planned decommissioning in 2025, and we find there is a 92% probability that benefits exceed its costs, with an expected net present value (NPV) of about 3 billion €, not including the unpredictable economic value of discovery of any new physics. We argue that the evaluation approach proposed here can be replicated for any large-scale research infrastructure, thus helping the decision-making on competing projects, with a socio-economic appraisal complementary to other evaluation criteria.

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Additional reading:

Schopper, Herwig, 2016. "Some remarks concerning the cost/benefit analysis applied to LHC at CERN," Technological Forecasting and Social Change, Elsevier, vol. 112(C), pages 54-64.

E Pugliese, G Cimini, A Patelli, A Zaccaria, L Pietronero, A Gabrielli, Unfolding the innovation system for the development of countries: co-evolution of Science, Technology and Production, arXiv preprint arXiv:1707.05146

A Patelli, G Cimini, E Pugliese, A Gabrielli, The scientific influence of nations on global scientific and technological development, Journal of Informetrics 11, 1229-1237 (2017)

Over **70 companies and institutes produce accelerators for industrial applications**; these organizations sell more than **1,100 industrial systems per year** — almost twice the number produced for research or medical therapy — at a **market value of $2.2B**.

Over **$1B** of this amount is generated by the sales of accelerators for **ion implantation** into materials — primarily semiconductor devices — whose worldwide value of production is about $300B.

Hamm,R.andHamm,M.(2012).Industrial accelerators and their applications. World Scientific Publishing Co.

As of 2014 there were **42,200** accelerators worldwide:
27,000 (64%) in industry,
14,000 (33%) for medical purposes
1,200 (3%) for basic research.

These figures exclude electron microscopes and x–ray tubes, and the security and defense industries.

Chernyaev, A. P. and Varzar, S. M. (2014). Particle accelerators in modern world. Physics of Atomic Nuclei, 77(10):1203–1215.

Some updated figures in Doyle, McDaniel, Hamm, The Future of Industrial Accelerators and Applications, SAND2018-5903B

KNOWLEDGE TRANSFER through PROCUREMENT

Survey of companies involved in technology-intensive procurement contracts with CERN.
178 questionnaires analyzed, related to 503 MCHF procurement budget.

Technological learning	44%
Increased international exposure	42%
Developed new products	38%
Market learning	36%
Started new R&D teams	13%
Would have poorer technological performance without CERN	41%
Would have poorer sales performance without CERN	52%

Impact	% risposte positive/tot questionari
Technological competences	31%
Increased sales	28%
Positive return on image	25%
New partnerships/coolaborations	21%
Market learning	17%
New clients	14%
New activities	13%
Higher market shares	12%
New markets	11%

INFN

The HUMAN capital

(very hard to quantify but extremely impactful for particle physics)

Salary Differences Between Master's and Ph.D. Graduates

Average Work-Life Earnings After a Bachelor's Degree				
Major	Bachelor's Degree	Master's Degree	Doctorate Degree	% Difference in Doctorate/Master's Earnings
Biological Science	$2,288,000	$2,757,000	$3,511,000	27%
Business	$2,563,000	$3,257,000	$3,535,000	9%
Communications	$2,333,000	$2,552,000	$3,306,000	30%
Computers and Math	$3,044,000	$3,541,000	$3,890,000	10%
Education	$1,798,000	$2,260,000	$2,802,000	24%
Engineering	$3,349,000	$3,918,000	$4,176,000	7%
Liberal Arts	$2,046,000	$2,448,000	$2,705,000	10%
Literature	$2,083,000	$2,444,000	$2,755,000	13%
Physical Science	$2,527,000	$3,193,000	$3,825,000	20%
Psychology	$2,001,000	$2,366,000	$3,157,000	33%
Science and Engineering Related	$2,587,000	$2,925,000	$3,814,000	30%
Social Science	$2,406,000	$2,986,000	$3,490,000	17%
Visual Arts	$1,966,000	$2,227,000	$2,545,000	14%

Note: *This chart is for 25-64 year olds who are working full-time, year round*

Source: www.census.gov

Today:

> 3000 PhD students

in LHC experiments

https://www.wes.org/advisor-blog/salary-difference-masters-phd/

THE EUROATLANTIC UNION REVIEW, VOL. 1 NO. 2/2014

2007-2012: 831 Fellows finished their Fellowships

The study targeted the **288 (38%) former fellows that did not have any affiliation (staff, student, user, etc.) with CERN** at time of the survey

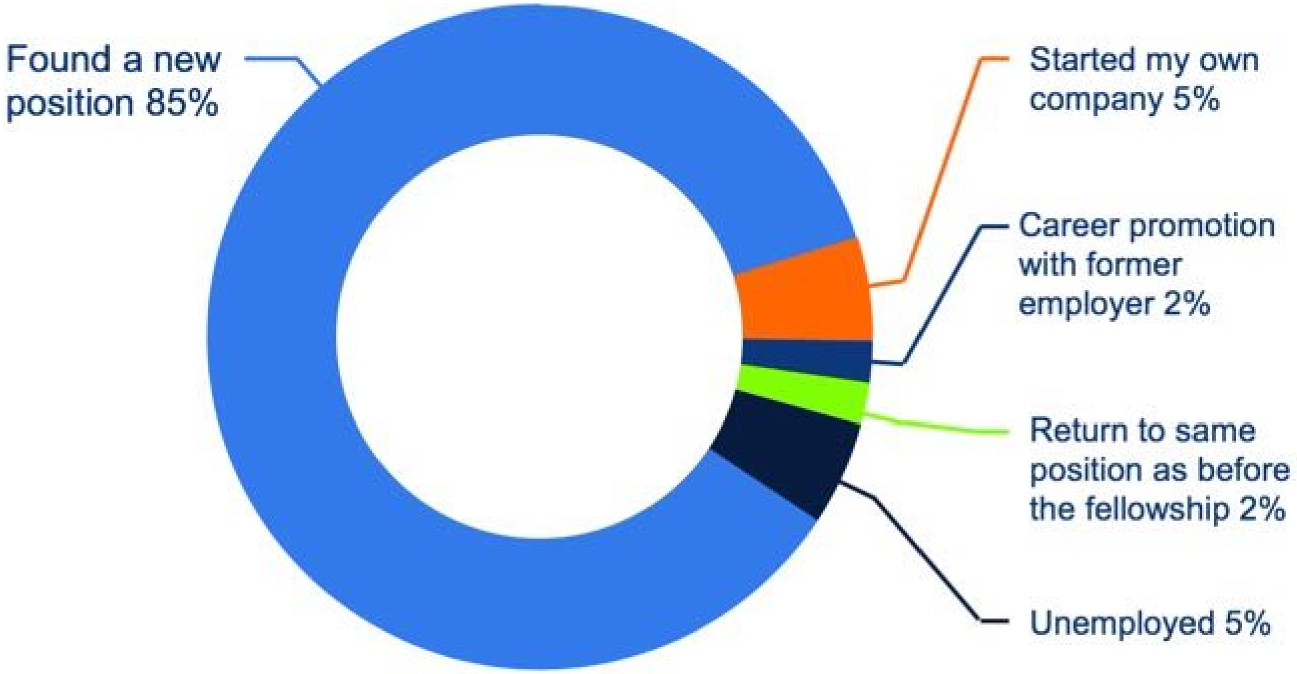
Basic Research, Knowledge Transfer and Labor Market: Evidence from CERN's Fellowship Programs

Silvia Bruzzi* and Giovanni Anelli**

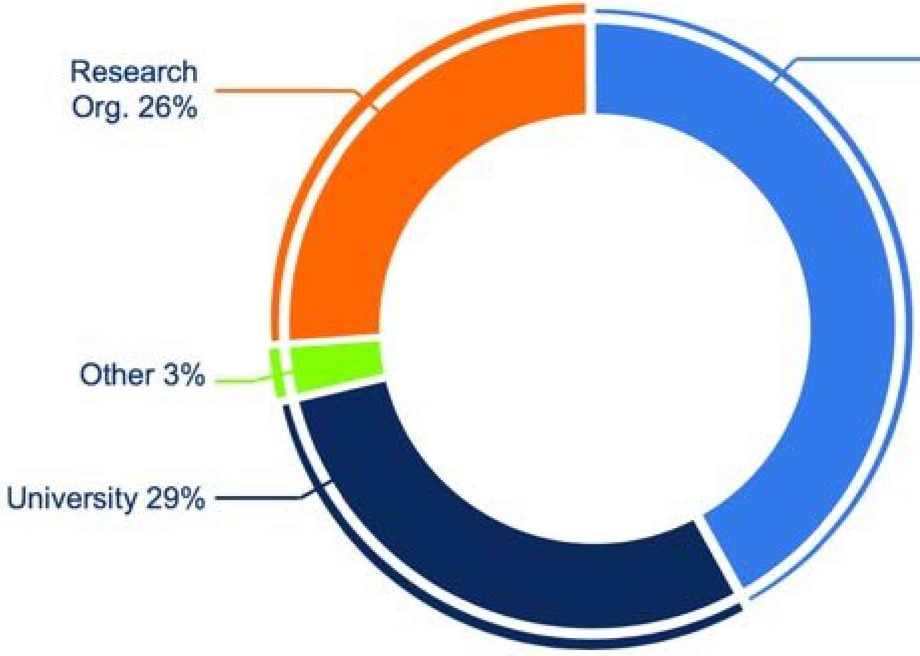
Abstract. *Nowadays, investing in scientific research to produce knowledge is considered a main asset for winning competition and contributing to the creation of economic value for the benefit of global society. Among the different phases of R&D, basic research stands out for its very high costs, risks and a time horizon of long/very long term. Nonetheless, if well-governed, it represents the component of R&D more able to produce positive externalities at a global level. In this framework, this paper aims to focus on the wide socio-economic value generated by basic research, conceived as an irreplaceable engine of innovation. In order to measure the performance of basic research, the paper proposes to refer to the outcome of research activity, i.e. the advancement of knowledge diffused by and through people, and discuss the results of a survey developed at CERN on the past-CERN Fellows, in order to isolate the contribution of the Fellowship Programs of CERN to the Fellows' professional career, in primis in industry. Our findings testify that basic research produces a continued scientific 'fertilisation effect' of the global economic system, contributing to the creation of high skilled and professionalized human resources to the benefit of industry and other employers, so generating positive externalities wider than those measured in terms of patents and publications, the metrics traditionally used to measure the performance of research.*

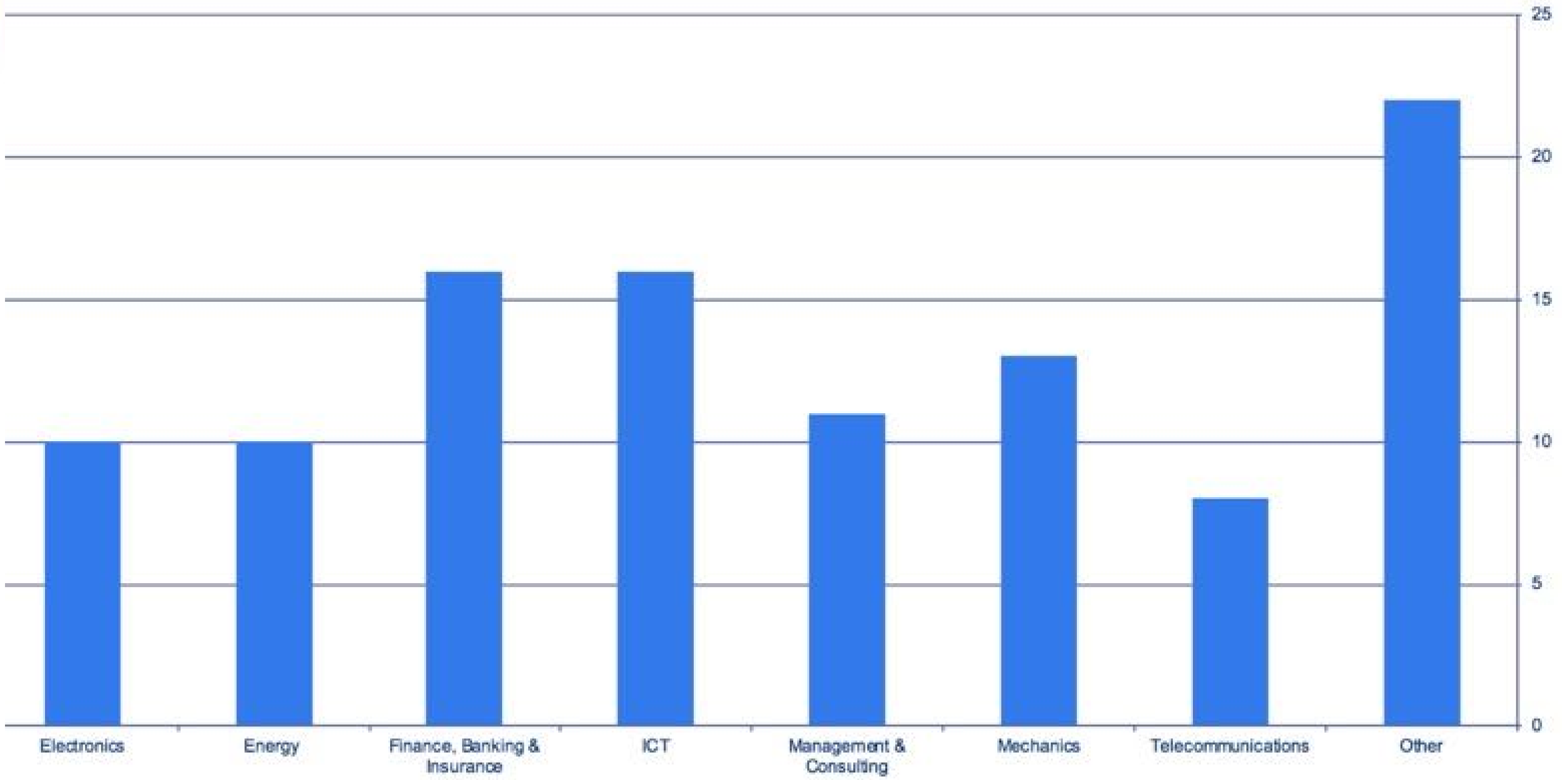
Keywords: *Basic Research; Knowledge Transfer; Labor Market; CERN.*

First Position after Fellowship



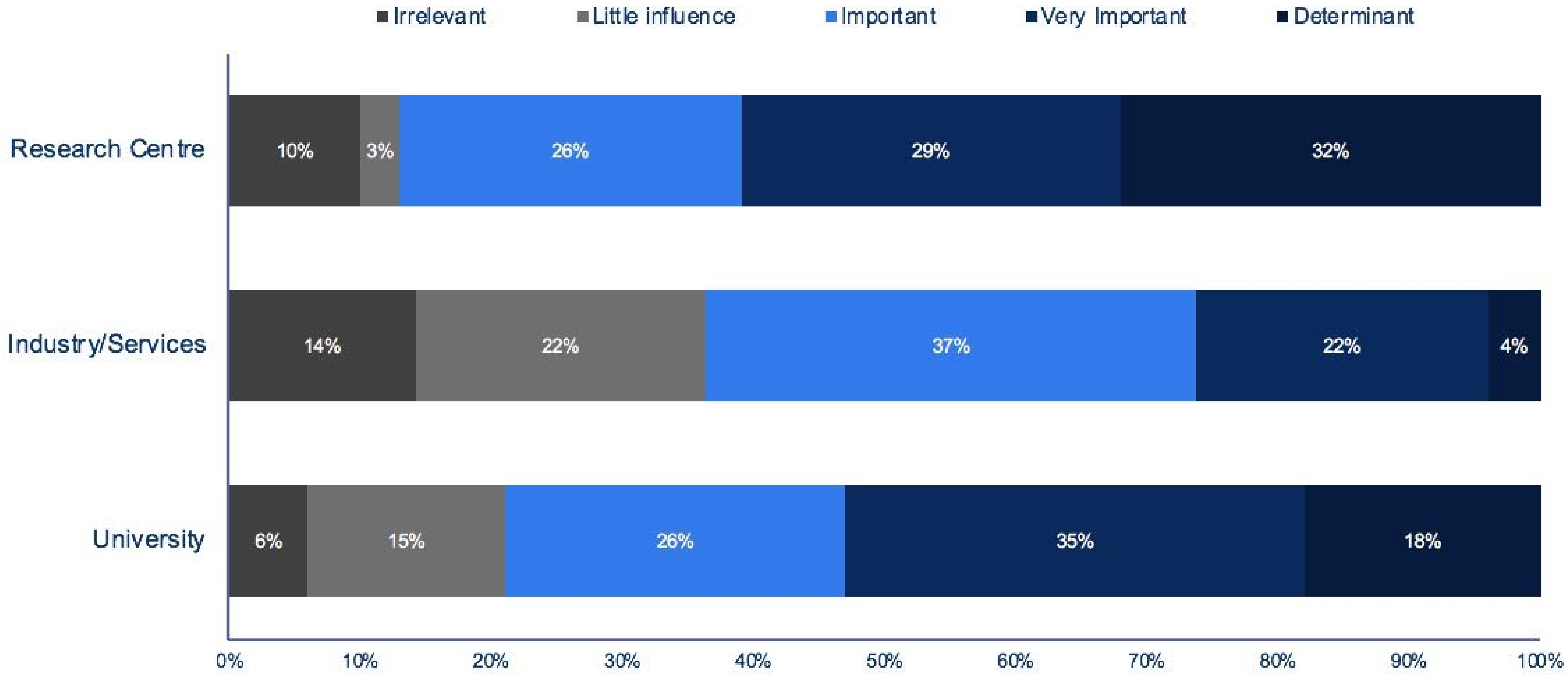
First Position after Fellowship



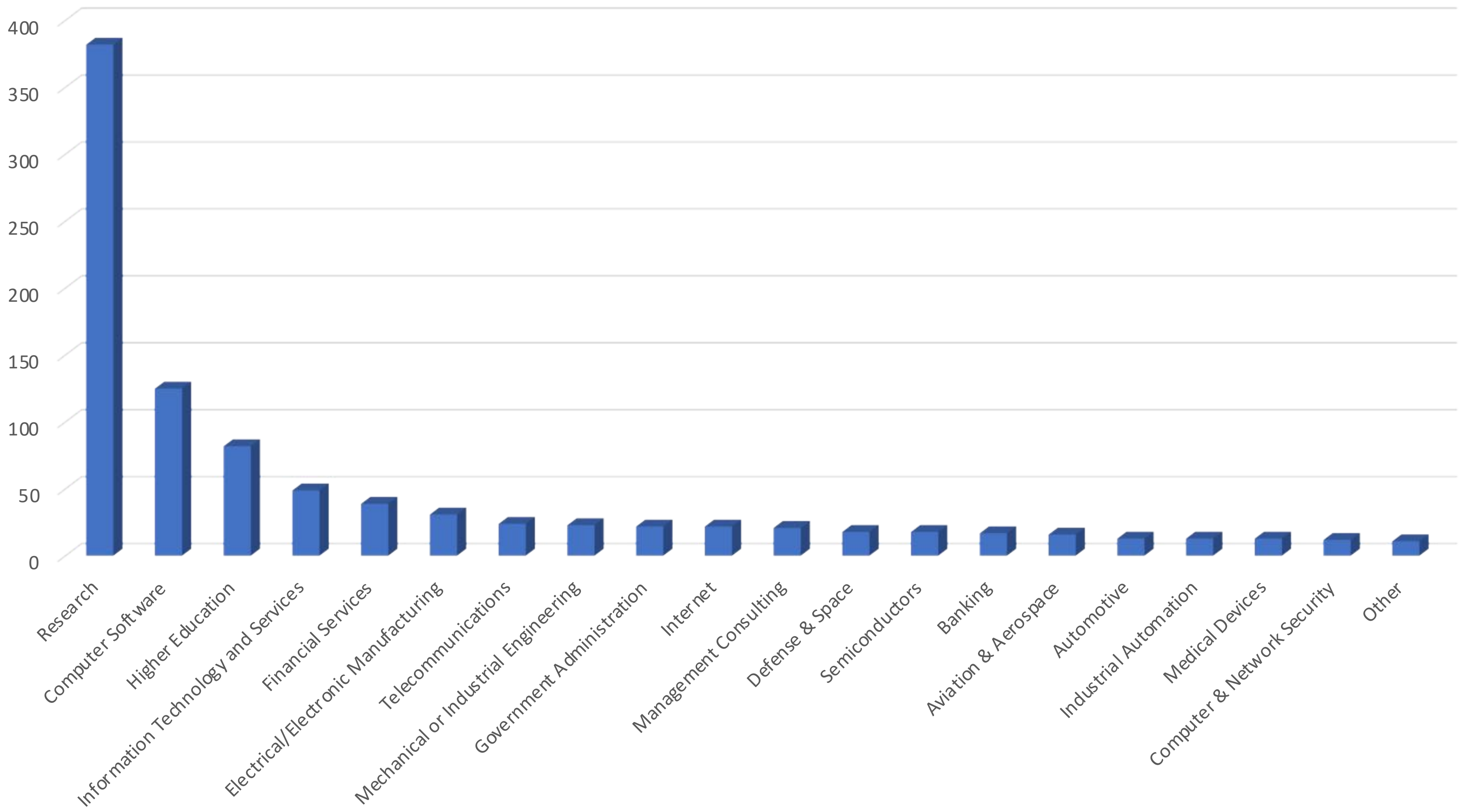


First Position after Fellowship

How important was the CERN fellowship
to secure your first position after the fellowship?

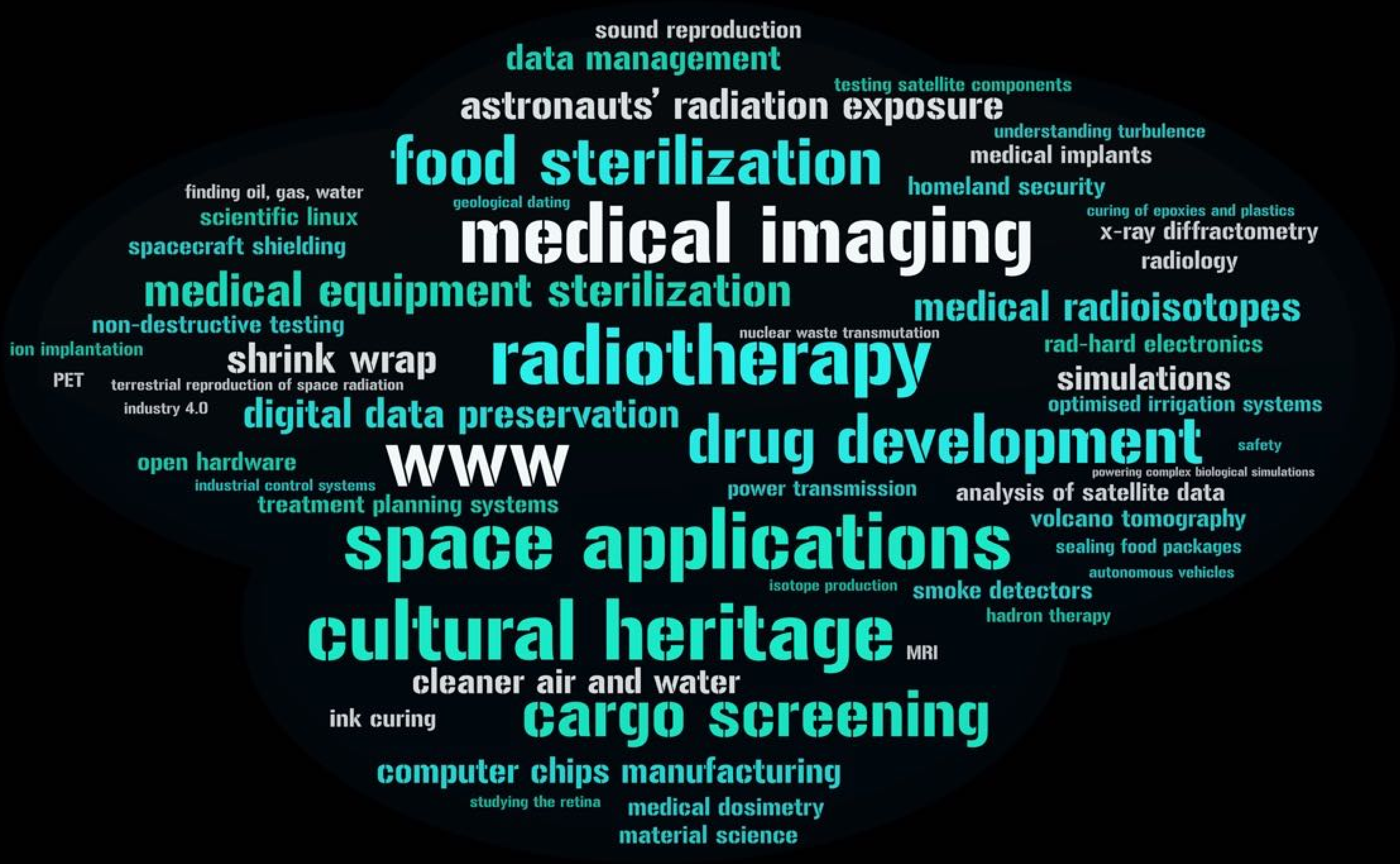


Top Twenty Industry Sectors of CERN Alumni Community:



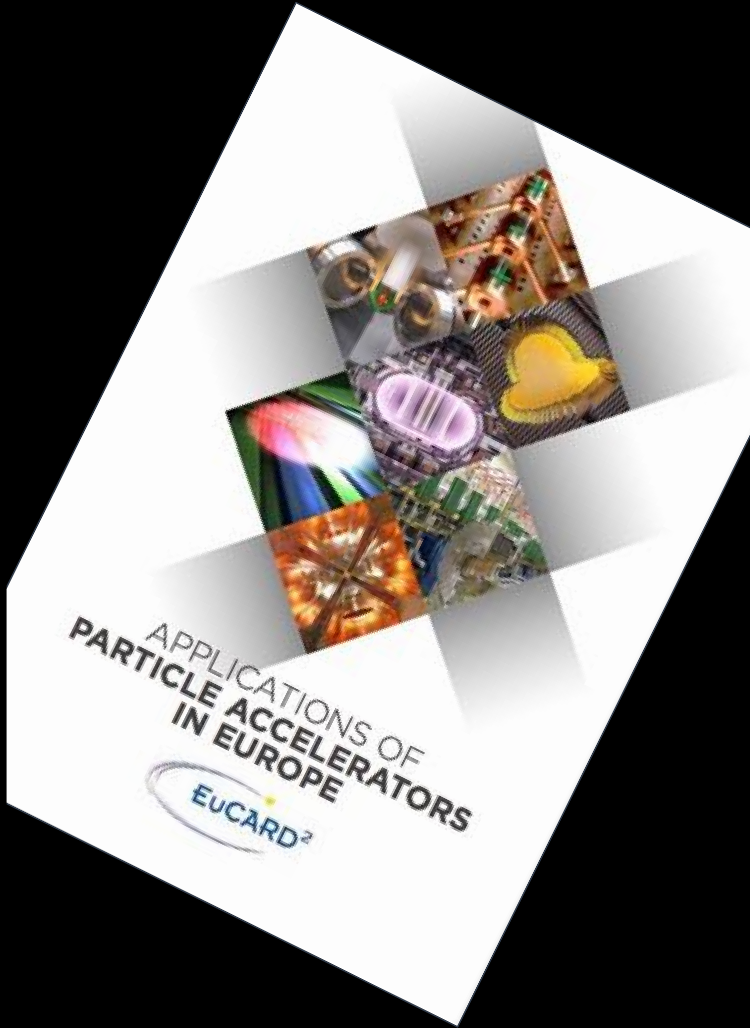
https://alumni.cern/signup

Technologies and know-how

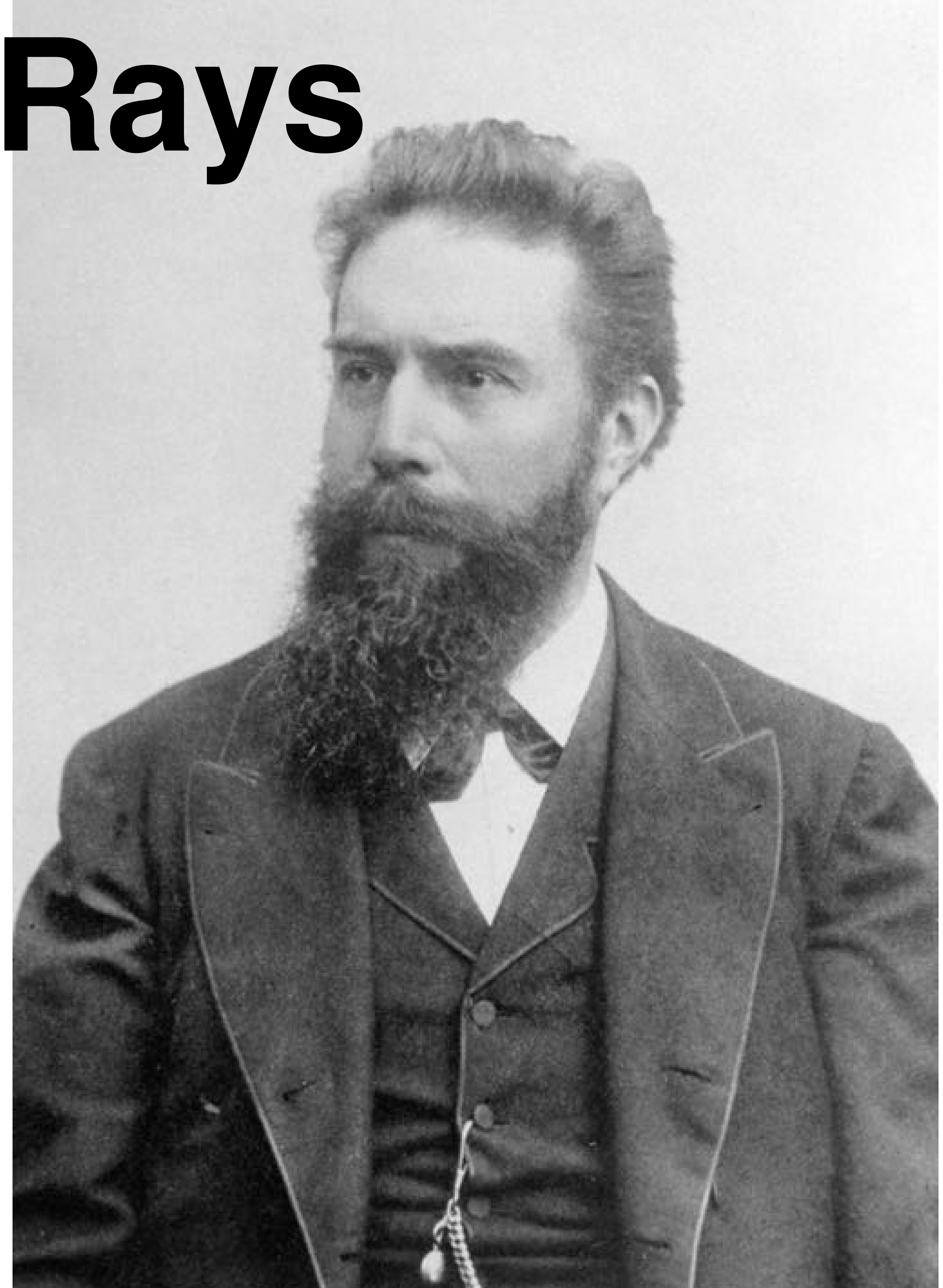

sound reproduction
data management
testing satellite components
astronauts' radiation exposure
understanding turbulence
food sterilization
medical implants
homeland security
finding oil, gas, water
geological dating
scientific linux
curing of epoxies and plastics
medical imaging
x-ray diffractometry
spacecraft shielding
radiology
medical equipment sterilization
medical radioisotopes
non-destructive testing
nuclear waste transmutation
ion implantation
rad-hard electronics
shrink wrap
radiotherapy
PET
terrestrial reproduction of space radiation
simulations
industry 4.0
optimised irrigation systems
digital data preservation
drug development
safety
WWW
open hardware
powering complex biological simulations
industrial control systems
power transmission
analysis of satellite data
treatment planning systems
volcano tomography
space applications
sealing food packages
autonomous vehicles
isotope production
smoke detectors
hadron therapy
cultural heritage
MRI
cleaner air and water
ink curing
cargo screening
computer chips manufacturing
studying the retina
medical dosimetry
material science

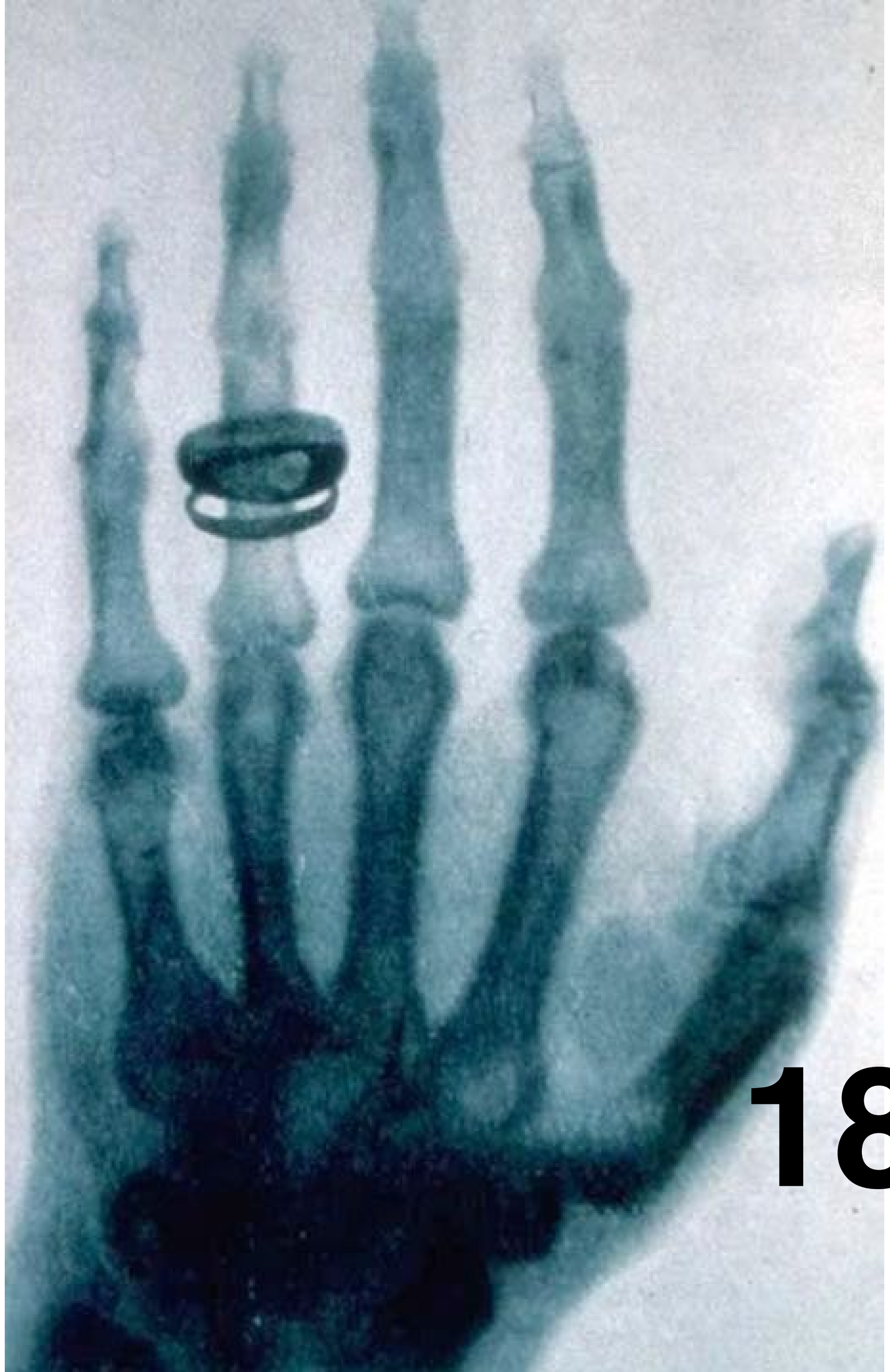

Accelerators for America's Future
U.S. DEPARTMENT OF ENERGY
Particle physics – it matters
A forward look at UK research into the building blocks of the Universe and its impact on society
In partnership with
Science & Technology Facilities Council
Accelerating science and innovation
Societal benefits of European research in particle physics
Tools, Techniques, and Technology Connections of Particle Physics
Task force chairs:
Marcel Demarteau
Argonne National Laboratory
Katie Yurkewicz
Fermi National Accelerator Laboratory
U.S. DEPARTMENT OF ENERGY
Office of Science
Accelerators and Beams
TOOLS OF DISCOVERY AND INNOVATION
4th Edition
Published by the Division of Physics of Beams of the American Physical Society
APPLICATIONS OF PARTICLE ACCELERATORS IN EUROPE
EuCARD²
Accelerators for Society
Particle accelerators are being applied throughout society. Originally developed for fundamental research, today they are used for a range of applications, from healthcare to manufacturing silicon chips to reducing pollution.
TIARA
From Physics to Daily Life
Applications in Informatics, Energy, and Environment
Edited by Beatrice Bressan
WILEY Blackwell

Area	Application	Beam	Accelerator	Beam energy/MeV	Beam current/ mA	Number
Medical	Cancer therapy	e	linac	4-20	10^{-2}	>14000
		p	cyclotron, synchrotron	250	10^{-6}	60
		C	synchrotron	4800	10^{-7}	10
	Radioisotope production	p	cyclotron	8-100	1	1600
Industrial	Ion implantation	B, As, P	electrostatic	< 1	2	>11000
	Ion beam analysis	p, He	electrostatic	<5	10^{-4}	300
	Material processing	e	electrostatic, linac, Rhodatron	≤10	150	7500
	Sterilisation	e	electrostatic, linac, Rhodatron	≤10	10	3000
Security	X-ray screening of cargo	e	linac	4-10	?	100?
	Hydrodynamic testing	e	linear induction	10-20	1000	5
Synchrotron light sources	Biology, medicine, materials science	e	synchrotron, linac	500-10000		70
Neutron scattering	Materials science	p	cyclotron, synchrotron, linac	600-1000	2	4
Energy – fusion	Neutral ion beam heating	d	electrostatic	1	50	10
	Heavy ion inertial fusion	Pb, Cs	Induction linac	8	1000	Under development
	Materials studies	d	linac	40	125	Under development
Energy – fission	Waste burner	p	linac	600-1000	10	Under development
	Thorium fuel amplifier	p	linac	600-1000	10	Under development
Energy – bio-fuel	Bio-fuel production	e	electrostatic	5	10	Under development
Environmental	Water treatment	e	electrostatic	5	10	5
	Flue gas treatment	e	electrostatic	0.7	50	Under development

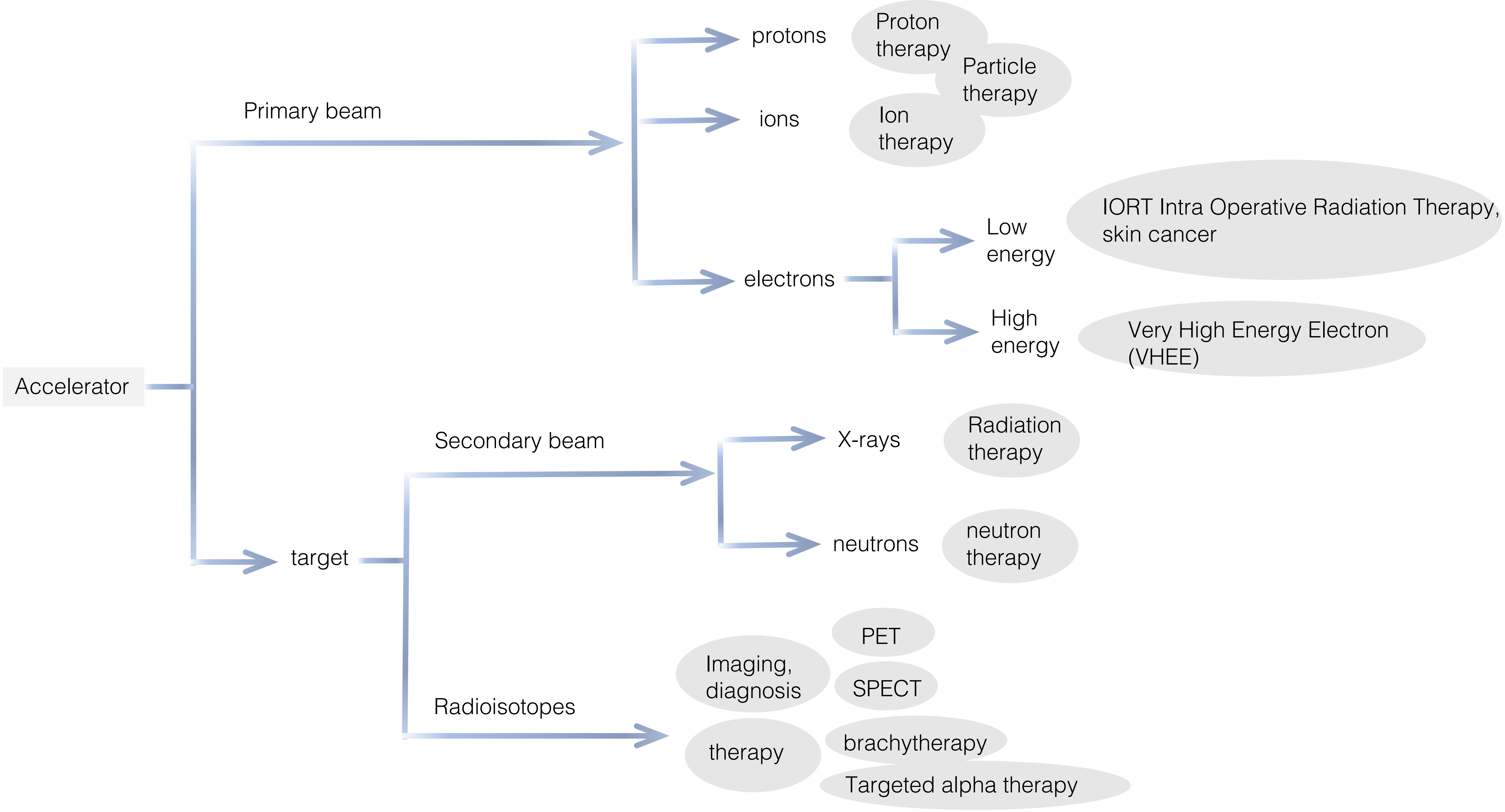


X-Rays





1895



Accelerator
Primary beam
protons
Proton therapy
Particle therapy
ions
Ion therapy
electrons
Low energy
IORT Intra Operative Radiation Therapy, skin cancer
High energy
Very High Energy Electron (VHEE)
target
Secondary beam
X-rays
Radiation therapy
neutrons
neutron therapy
Radioisotopes
Imaging, diagnosis
PET
SPECT
therapy
brachytherapy
Targeted alpha therapy

Radiotherapy

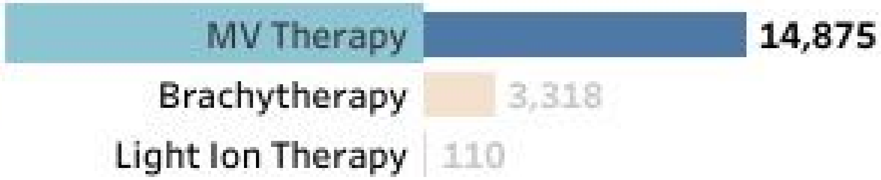
Status of Radiation Therapy Equipment

155
Countries

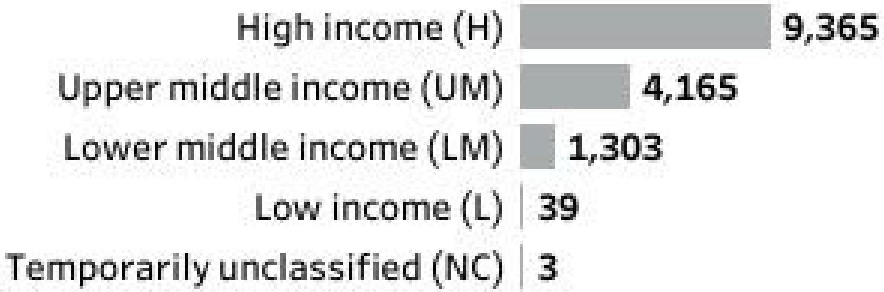
7602
RT Centres

14875
MV Therapy

Equipment type
(Updated on : 23/06/2021 09:19:53)



Equipment per income groups
(Updated on : 23/06/2021 09:19:53)



IAEA | DIRAC Directory of RAdiotherapy Centres

Status of Radiation Therapy Equipment

155 Countries

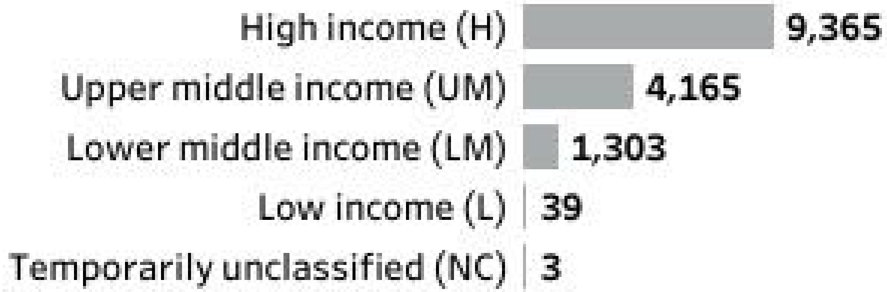
7602 RT Centres

14875 MV Therapy

STELLA Collaboration formed to address the lack of radiotherapy in challenging environments. Supported by ICEC, UK STFC, Lancaster and Oxford University, CERN, users in LMICs

14,875

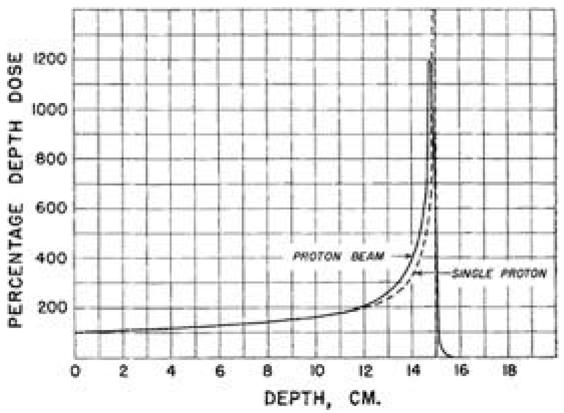
(Updated on : 23/06/2021 09:19:53)

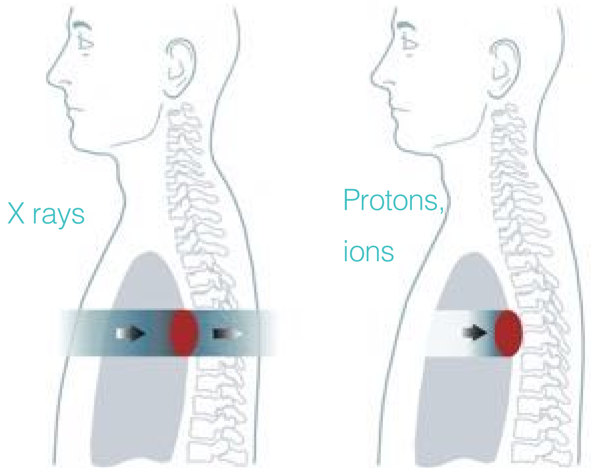


IAEA | DIRAC Directory of RAdiotherapy Centres

Berkeley

1931 Invention of cyclotron (Ernest Lawrence)
1946 RR Wilson published his seminal paper on particle therapy
1952 First biological investigation with accelerated nuclei (C Tobias and JH Lawrence)
1954 First therapeutic exposure of humans to protons and alphas (Tobias and JH Lawrence)
1975 Clinical trials with accelerated light ions at LBL (Castro)





Gustav Werner Institute and Theodor Svedberg Laboratory

1949 Synchrocyclotron at the Gustav Werner Institute (Uppsala)
1950s Pre-therapeutic physical experiments with high energy protons (B. Larsson)
1957 First patient treated with proton beam

Status of Radiation Therapy Equipment

20 Countries

106 RT Centres

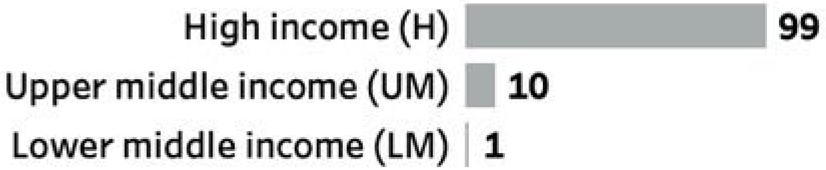
110 Light Ion Therapy

Equipment type

(Updated on : 23/06/2021 09:19:53)

Equipment per income groups

(Updated on : 23/06/2021 09:19:53)



IAEA | DIRAC Directory of RAdiotherapy Centres

Protons: the LINAC way

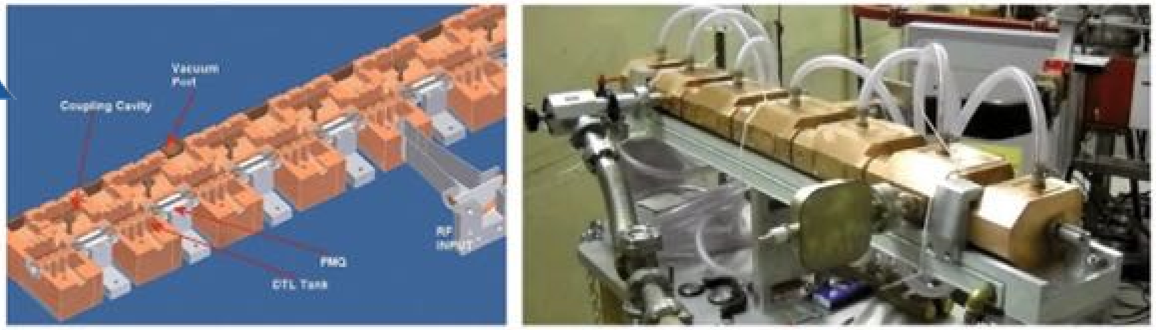
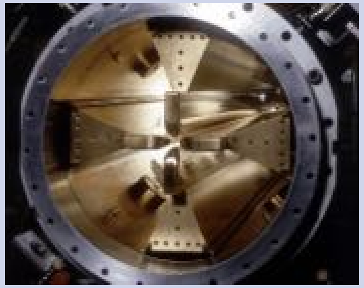


Fig. 4. TOP-IMPLART SCDTL structure: (left) schematic (right) 18–24 MeV booster built for the SPARKLE Company.

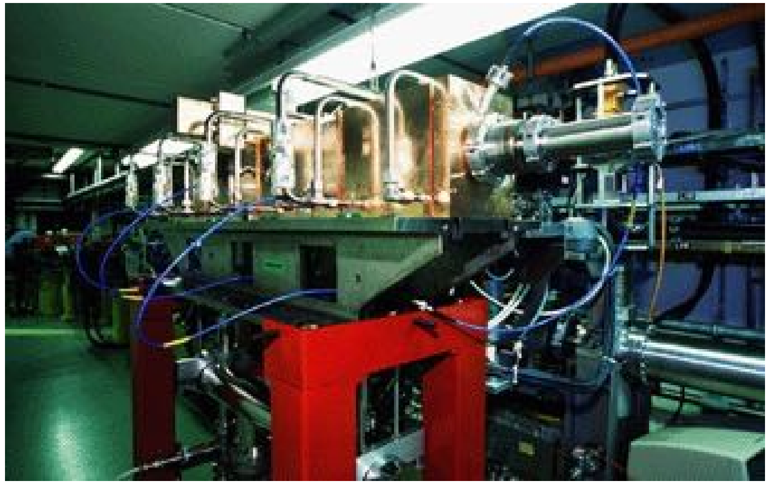
1990 **RFQ2** **200 MHz** **0.5 MeV /m** **Weight :1200kg/m** **Ext. diametre : ~45 cm**	**2007** **LINAC4 RFQ** **352 MHz** **1MeV/m** **Weight : 400kg/m** **Ext. diametre : 29 cm**	**2014** **HF RFQ** **750MHz** **2.5MeV/m** **Weight : 100 kg/m** **Ext. diametre : 13 cm**
		

TOP IMPLART

L. Picardi, C. Ronsivalle, A. Vignati, Progetto del TOP Linac, ENEA Technical Report RT/INN/97/17 (in Italian) (1997)
C. Ronsivalle, M. Carpanese, C. Marino, G. Messina, L. Picardi, S. Sandri, E. Basile, B. Caccia, D.M. Castelluccio, E. Cisbani, S. Frullani, F. Ghio, V. Macellari, M. Benassi, M. D'Andrea, L. Strigari, The TOP-IMPLART project, Eur. Phys. J. Plus 126: 68 (2011) 1–15, http://dx.doi.org/10.1140/epjp/i2011-11068-x.

Compact High-Frequency Radio Frequency Quadrupole (RFQ)

M. Vretenar, A. Dallocchio, V. A. Dimov, M. Garlasché, A. Grudiev, A. M. Lombardi, S. Mathot, E. Montesinos, M. Timmins, "A Compact High-Frequency RFQ for Medical Applications", in Proc. LINAC2014, Geneva, Switzerland, September 2014



LInac BOoster (LIBO)

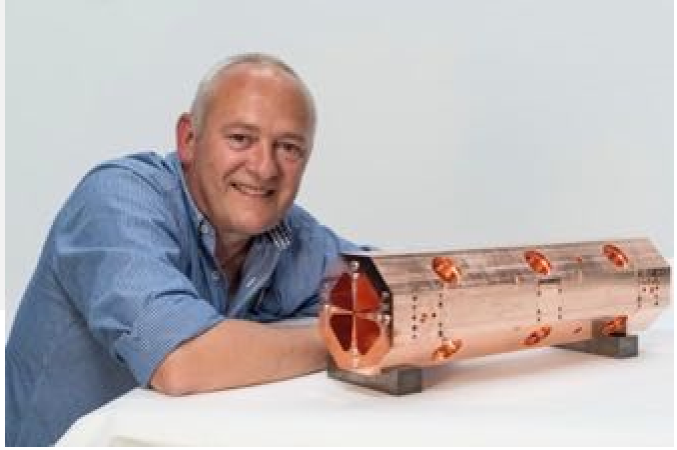
U. Amaldi et al., LIBO: a 3 GHz proton linac booster of 200 MeV for cancer treatment, in Proceedings of the XIX International Linear Accelerator Conference, Chicago, (1998), p. 633U. Amaldi et al., "LIBO-a linac booster for protontherapy: construction and test of a prototype," Nucl. Instrum. Methods Phys. Res. A, vol. 521, pp. 512-529, 2004.

Toward clinical proton therapy LINACs

The RFQ accelerating structure entirely manufactured by AVO (under CERN licence) has completed the Factory Acceptance Testing protocols and is RF tuned.

The RFQ is ready to be installed into the beamline at STFC (Daresbury) AVO integration site in the next weeks.

ADVANCED ONCOTHERAPY · ADAM an ADVANCED ONCOTHERAPY company · LiGHT Linac for Image Guided Hadron Therapy



CERN proton therapy RFQ (5 MeV / 2m)

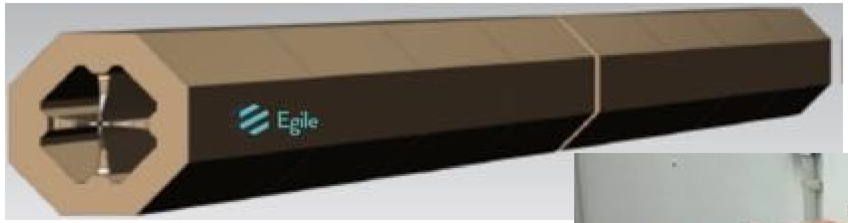
TOP IMPLART under development and construction by ENEA in collaboration with the Italian Institute of Health (ISS) and the Oncological Hospital Regina Elena-IFO.
Status in March 2021*: running at 55.5 MeV

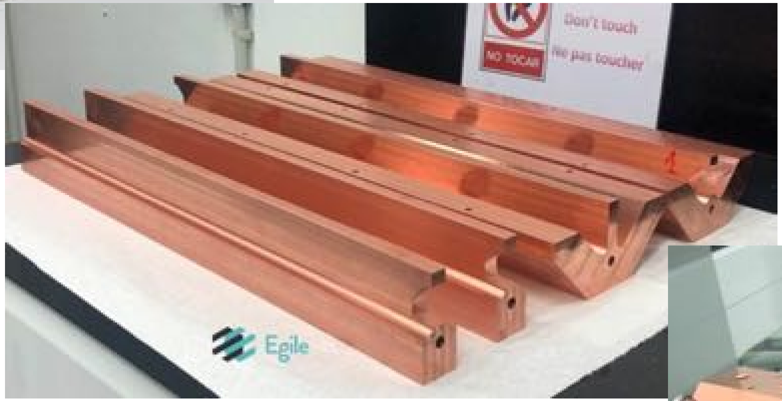
*http://www.frascati.enea.it/accelerators/Sito/TopImplartStatus&Schedules/index.htm

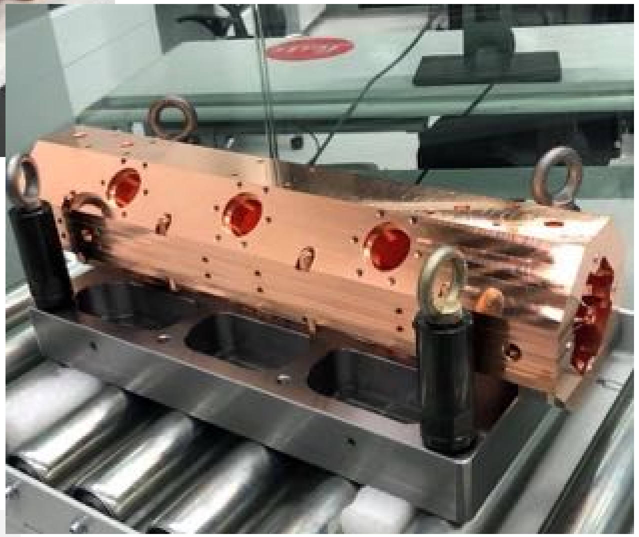
ERHA (Enhanced Radiotherapy with Hadrons) is the innovative proton therapy system being developed by LinearBeam for the treatment of tumors.
Collaboration with (among others) ENEA, INFN.

LinearBeam PROTONS FOR LIFE

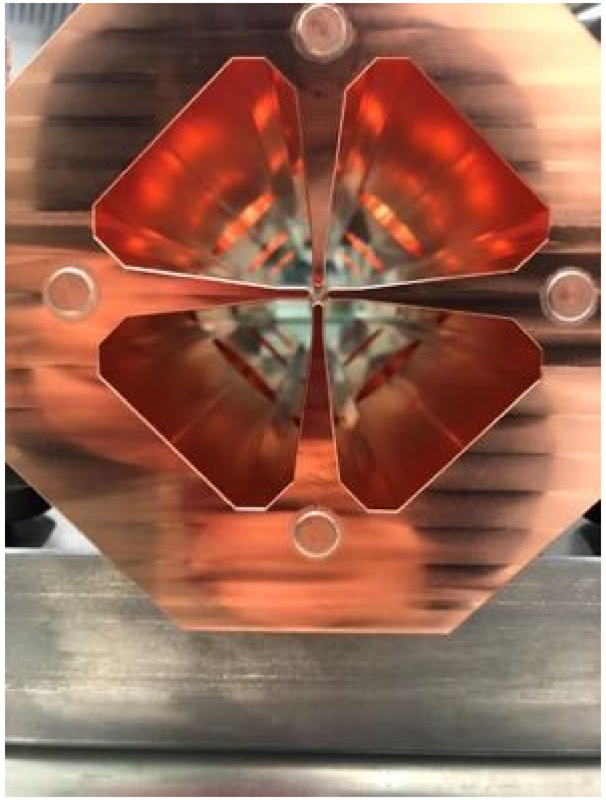
Next challenge: Carbon and other ions





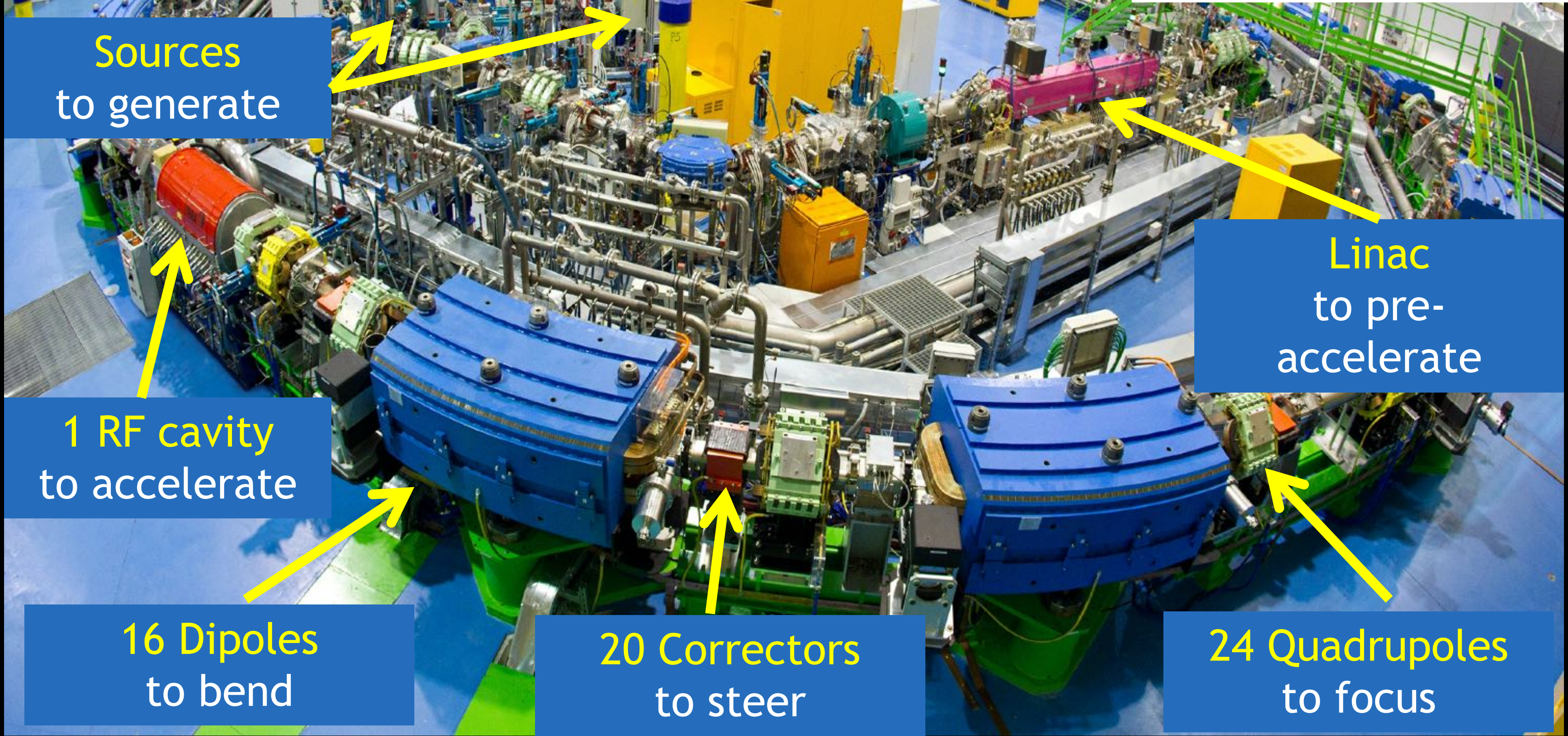


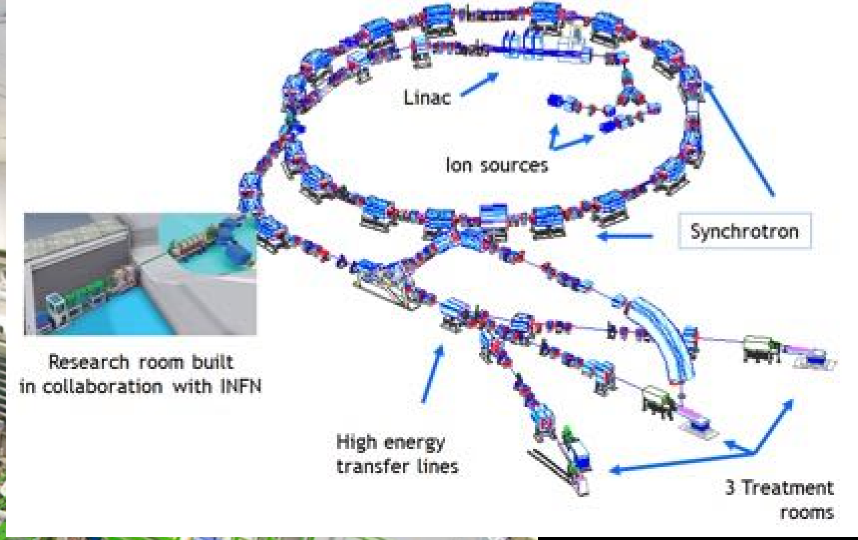
First (of 4 sections) completed



Collaboration CERN-CIEMAT-CDTI-Spanish industry
2.0 m long
750 MHz
Will deliver Carbon (or Helium) at 5 MeV (total energy)
Designed at CERN built in Spanish Industry

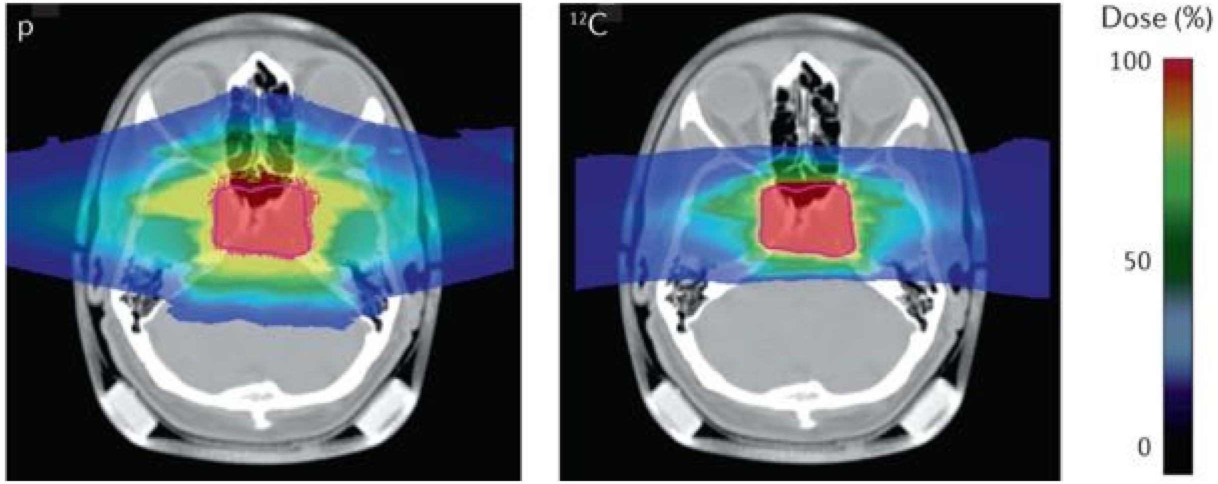
fondazione CNAO





From pioneering rasterscanning & carbon ion pilot project @ GSI

440 patients
1998-2008



The image shows an optimized plan with two opposite fields for a chordoma patient using protons (left) or 12C ions (right).

Since 2009*:
2841 patients with p
3793 patients with C-ion

* Until Dec 2020, source ptcog.ch

From PIMMS @ CERN → TERA

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN - PS DIVISION

CERN/PS 2000-007 (DR)

PROTON-ION MEDICAL MACHINE STUDY (PIMMS) PART II

Accelerator Complex Study Group*
supported by the Med-AUSTRON, Onkologie-2000 and the TERA Foundation
and hosted by CERN

ABSTRACT

The Proton-Ion Medical Machine Study (PIMMS) group was formed following an agreement between the Med-AUSTRON (Austria) and the TERA Foundation (Italy) to combine their efforts in the design of a cancer therapy synchrotron capable of accelerating either light ions or protons. CERN agreed to support and host this study in its PS Division. A close collaboration was also set up with GSI (Germany). The study group was later joined by Onkologie-2000 (Czech Republic). Effort was first focused on the theoretical understanding of slow extraction and the techniques required to produce a smooth beam spill for the conformal treatment of complex-shaped tumours with a sub-millimetre accuracy by active scanning with proton and carbon ion beams. Considerations for passive beam spreading were also included for protons. The study has been written in two parts. The more general and theoretical aspects are recorded in Part I and the specific technical design considerations are presented in the present volume, Part II. An accompanying CD-ROM contains supporting publications made by the team and data files for calculations. The PIMMS team started its work in January 1996 in the PS Division and continued for a period of four years.

*Full-time members: L. Badano[1)], M. Benedikt[2)], P.J. Bryant[2)] (Study Leader), M. Crescenti[1)], P. Holy[3)], A. Maier[2)+4)], M. Pullia[1)], S. Reimoser[2)+4)], S. Rossi[1)],
Part-time members: G. Borri[1)], P. Knaus[1)+2)]
Contributors: F. Gramatica[1)], M. Pavlovic[4)], L. Weisser[5)]
1) TERA Foundation, via Puccini. 11, I-28100 Novara.
2) CERN, CH 1211 Geneva-23.
3) Oncology-2000 Foundation, Na Morani 4, CZ-12808 Prague 2.
4) Med-AUSTRON, c/o RIZ, Prof. Dr. Stephan Korenstr.10, A-2700 Wr. Neustadt.
5) Sommer & Partner Architects Berlin (SPB), Hardenbergplatz 2, D-10623 Berlin.

Geneva, Switzerland
May 2000

INFN

fondazione CNAO

MedAustron

Patient treatment at MedAustron

Since 2016:
1174 Patients
30600 Single Fractions

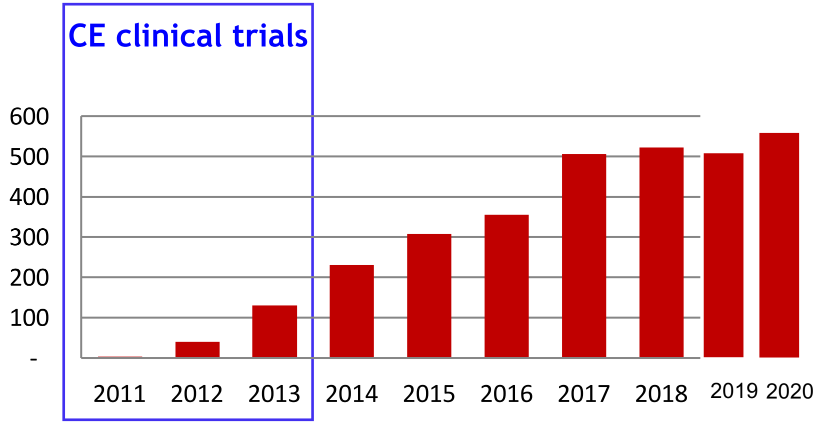
CNS	28%
Head & Neck	20%
Pediatrics	15%
Re-Irradiation	15%
Sarcoma	9%
Skull Base	7%
Prostate	3%
Gastrointestinal (upper)	2%
Gastrointestinal (lower)	<1%
Gynecological Tumors	<1%
Urogenital Tumors	<1%
Breast/Mamma-Ca	<1%

Values October 2021 • values rounded

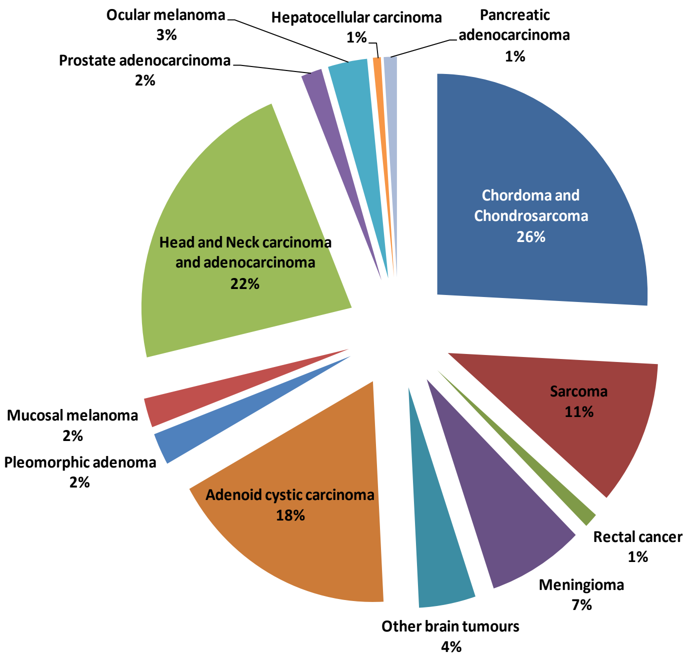
MedAustron

Patient treatment at CNAO

Since 2011:
3700 Patients
55% C-ions
45% Protons



Patients per year



Non oncological application: ventricular arrhythmia
(Collaboration with San Matteo Hospital, Pavia)
Published: European Journal of Heart Failure

fondazione CNAO

Challenges for next-generation ion-therapy machines

Cost-effective technologies

Reduced footprint

New treatment regimes (e.g. FLASH, microbeams) and fractionation schedules

Multi-ions

Radiobiology research integrated in the facility

Vozenin et al
Clin Cancer Res 2018


Contents lists available at ScienceDirect
Radiotherapy and Oncology
journal homepage: www.thegreenjournal.com

Original Article

Treatment of a first patient with FLASH-radiotherapy

Jean Bourhis[a,b,*], Wendy Jeanneret Sozzi[a], Patrik Gonçalves Jorge[a,b,c], Olivier Gaide[d], Claude Bailat[c], Fréderic Duclos[a], David Patin[a], Mahmut Ozsahin[a], François Bochud[c], Jean-François Germond[c], Raphaël Moeckli[c,1], Marie-Catherine Vozenin[a,b,1]

[a] Department of Radiation Oncology, Lausanne University Hospital and University of Lausanne; [b] Radiation Oncology Laboratory, Department of Radiation Oncology, Lausanne University Hospital and University of Lausanne; [c] Institute of Radiation Physics, Lausanne University Hospital and University of Lausanne; and [d] Department of Dermatology, Lausanne University Hospital and University of Lausanne, Switzerland

Fig. 1. Temporal evolution of the treated lesion: (a) before treatment; the limits of th PTV are delineated in black; (b) at 3 weeks, at the peak of skin reactions (grade 1 epithelitis NCI-CTCAE v 5.0); (c) at 5 months.

First human patient – skin cancer treated with 10 MeV-range electrons

(European) technologies for next-generation ion-therapy machines

Many challenges in common with those for future particle physics facilities. Various initiatives starting/on-going:

The Next Ion Medical Machine Study (NIMMS) collaborative study coordinated by CERN

H2020 HITRIplus project (CNAO, Bevatech, CEA, CERN, CIEMAT, Cosylab, GSI, INFN, MedAustron, PSI, Riga, UKGM, UKHD/HIT, Malta, Marburg, Uppsala, Wigner)

EC-funded study for SEEIIST (CERN, GSI)

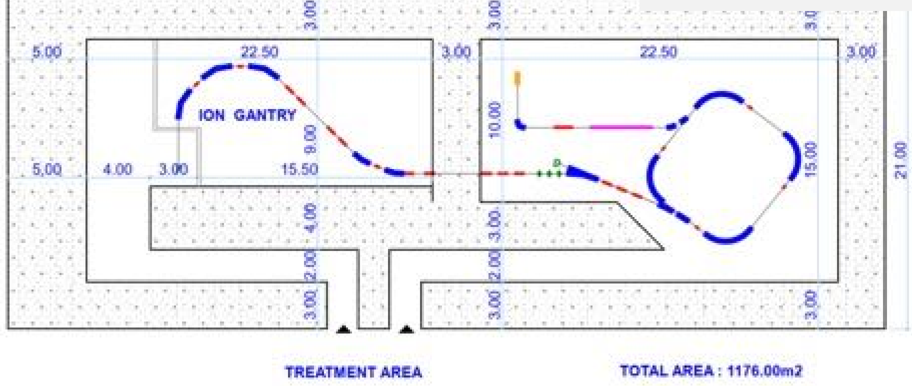
Ion superconducting gantry (CERN, CNAO, MedAustron, INFN)

Ion linac injector (CERN, CIEMAT)

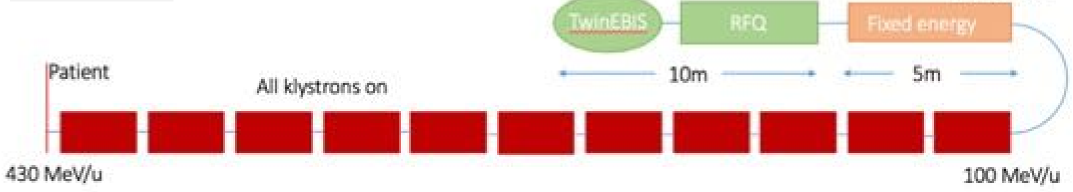
Dedicated WP on magnets for medical accelerators in H2020 IFAST project (GSI, BI, BT, CERN, HIT, CERN, CEA, INFN, CIEMAT, Wigner, UU, PSI, Scanditronix, Elytt, SigmaPhi)

SIG Superconducting Ion Gantry project (INFN)

Synchrotron design

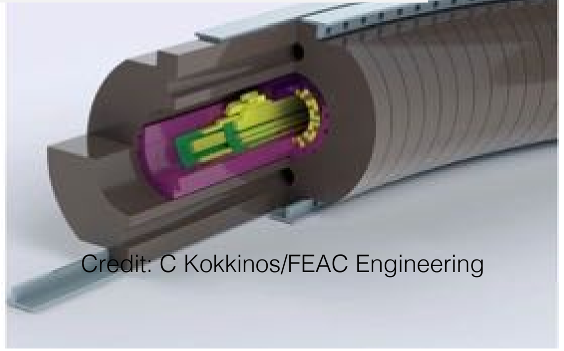


LINACs



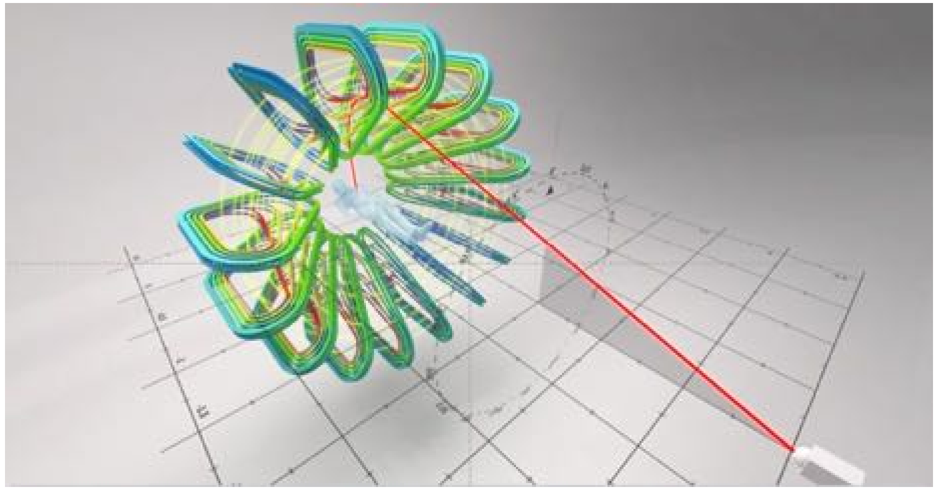
Gantries

Superconducting magnets



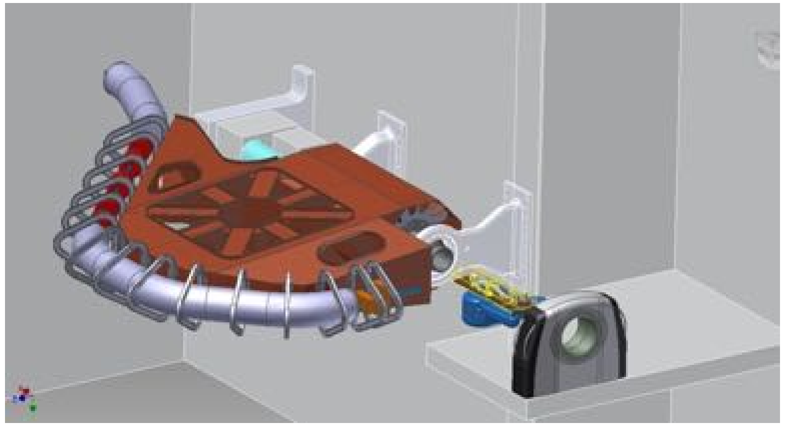
R&D on gantries

GaToroid: A Novel Concept for a Superconducting Compact and Lightweight Gantry for Hadron Therapy



CERN

Collaboration CNAO-INFN-CERN-MedAustron under discussion: start 2021, 4 years project



SIGRUM

Superconducting Ion Gantry with Riboni's Unconventional Mechanics

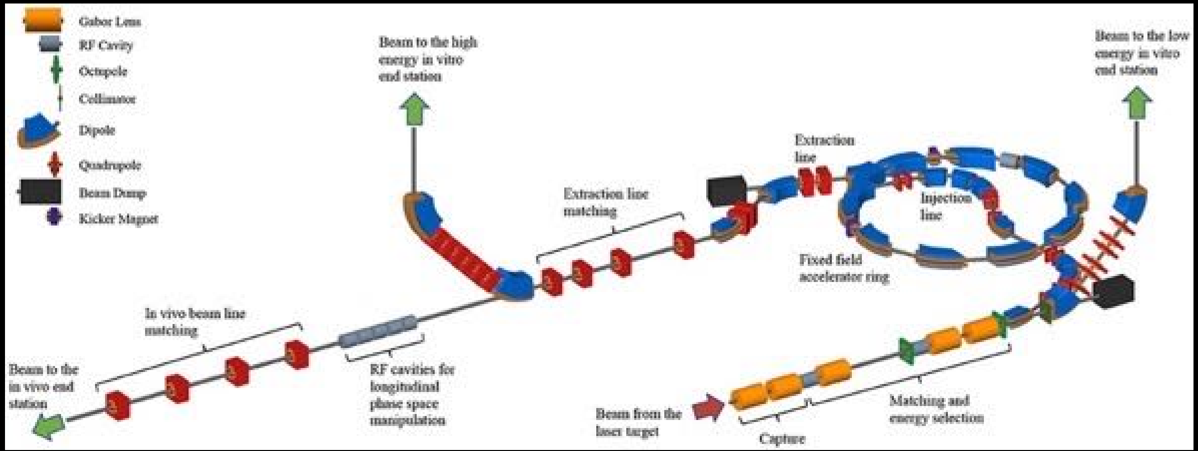
TERA CERN

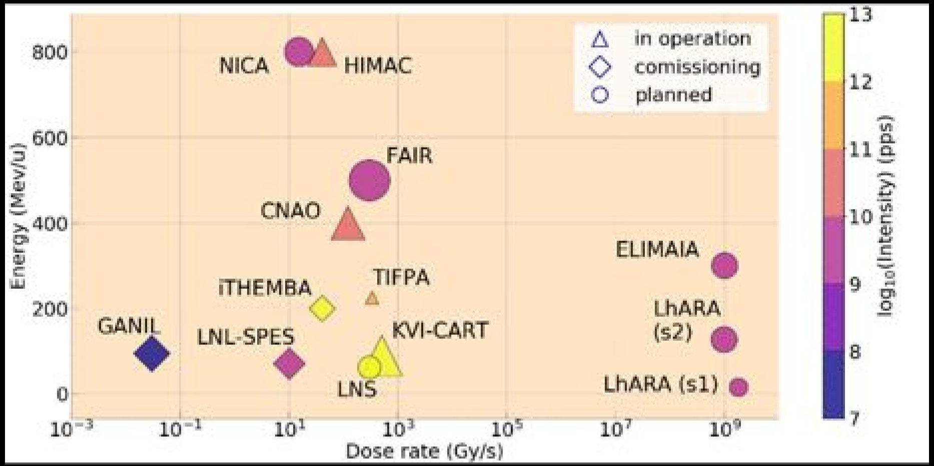
INFN

Approved for financing

Look even further

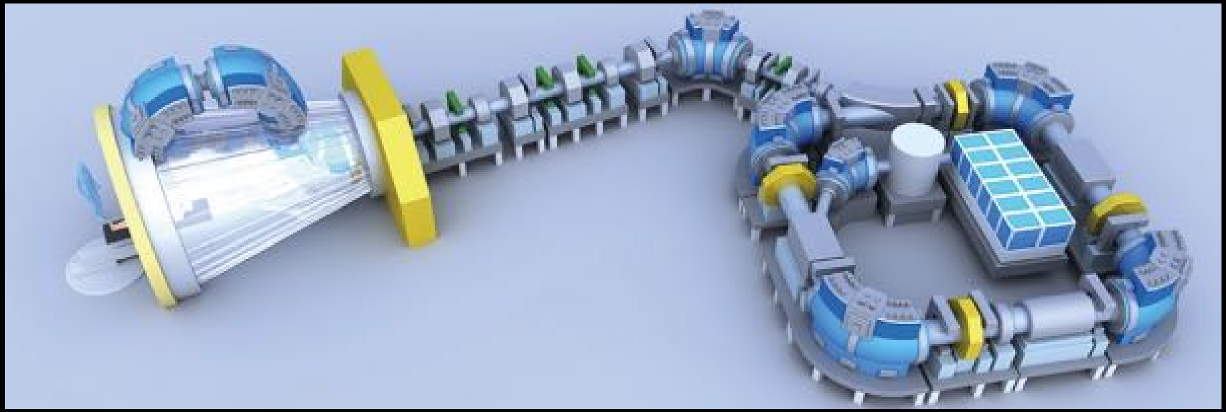
Laser-hybrid Accelerator for Radiobiological Applications





Credit: LhARA Consortium

Quantum Scalpel



5th generation facility:

Superconducting synchrotron

Multi-ion irradiation system

Injector with laser acceleration technology

Rotating gantry with HTS magnets

Microsurgery system

New treatment modalities:
Very High Energy Electrons (VHEE) + FLASH

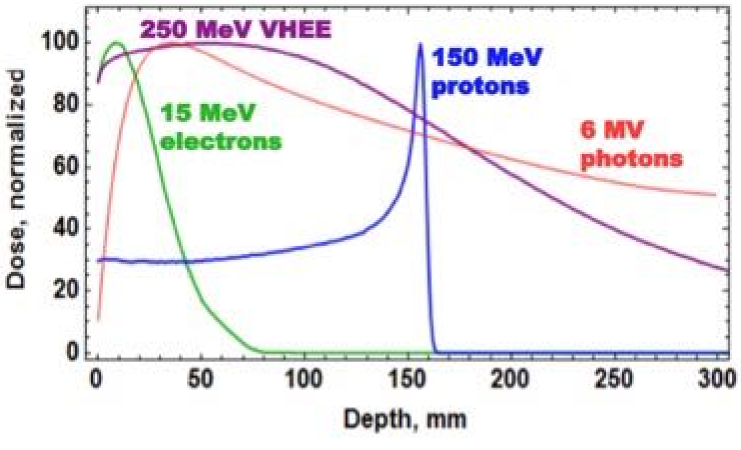
Experiments (including radiobiology) at various user facilities:

CERN Linear Electron Accelerator for Research (CLEAR)

VELA–CLARA at Daresbury Laboratory

PITZ at DESY

ELBE–HZDR in Dresden



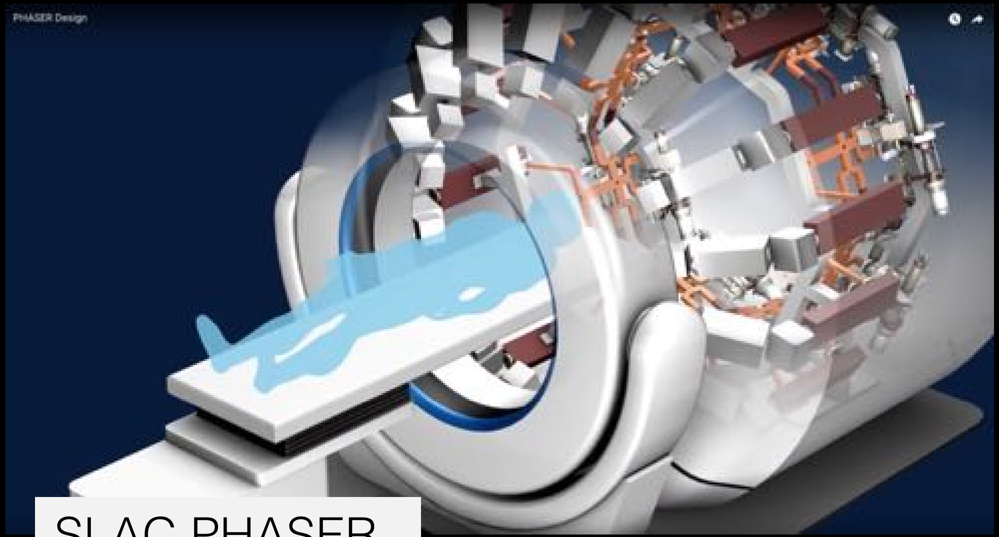
Dose profiles for various particle beams in water (beam widths $r = 0.5$ cm)

Facilities under design:

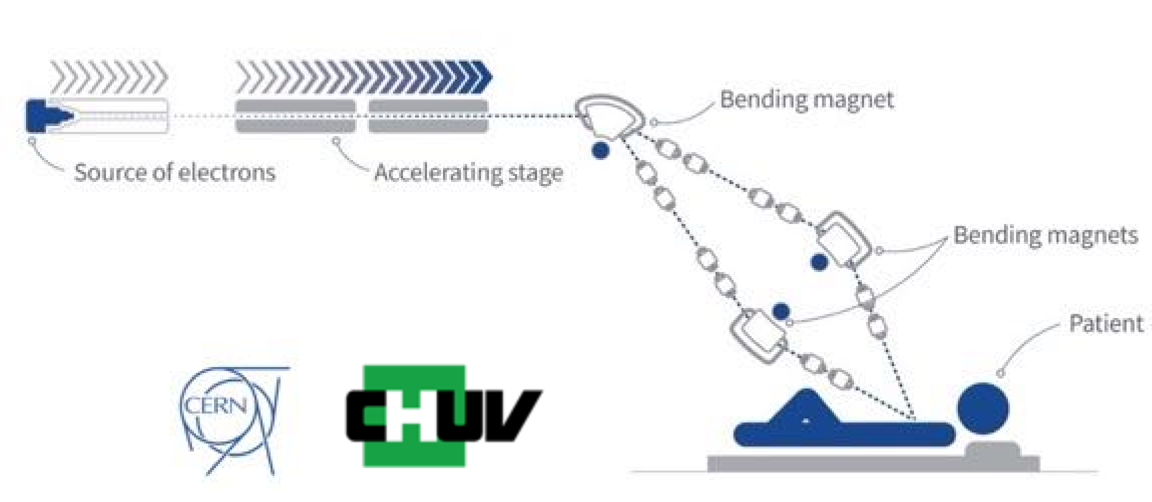
FRIDA Sapienza INFN

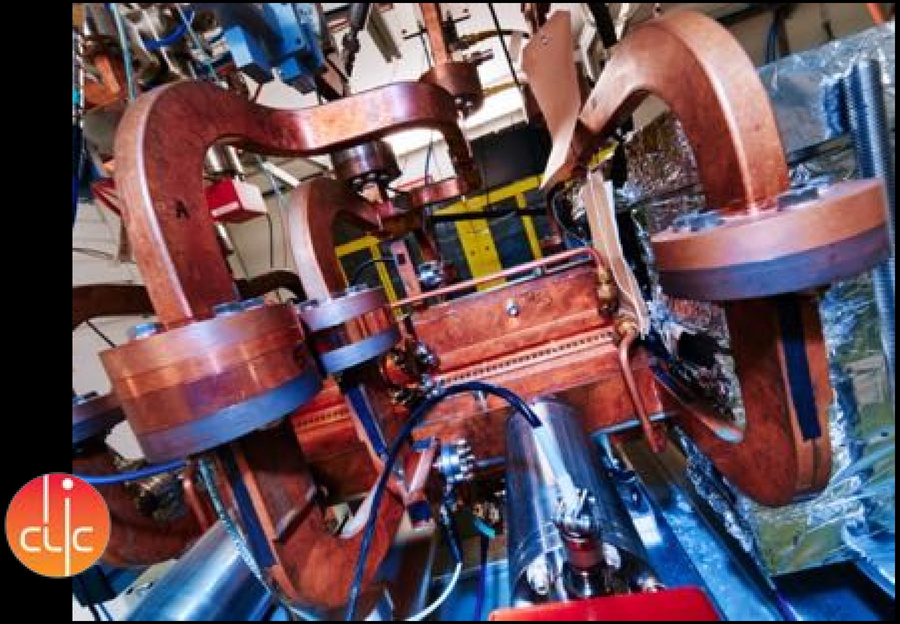
IDRA LOA Orsay

VHEE FLASH clinical facilities under design



SLAC PHASER





CERN – University Hospital Lausanne (CHUV) collaboration based on the CLIC technology (see talk from S.Stapnes)

Very intense electron beams
CLIC – to provide brightness needed for delicate physics experiments
FLASH – to provide dose fast for biological FLASH effect

Very precisely controlled electron beams
CLIC – to reduce the power consumption of the facility
FLASH – to provide reliable treatment in a clinical setting

High accelerating gradient
CLIC – fit facility in Lac Leman region and limit cost
FLASH – fit facility on typical hospital campuses and limit cost

Radioisotopes

nature International weekly journal of science

Home | News & Comment | Research | Careers & Jobs | Current Issue | Archive | Audio & Video | Fo

Archive > Volume 504 > Issue 7479 > News Feature > Article

NATURE | NEWS FEATURE

Radioisotopes: The medical testing crisis

With a serious shortage of medical isotopes looming, innovative companies are exploring ways to make them without nuclear reactors.

Richard Van Noorden

11 December 2013

PDF | Rights & Permissions

Radioisotopes & Nuclear Medicine

Established isotopes → Industrial suppliers

^{99m}Tc, ^{18}F, ^{123,125,131}I, ^{111}In, ^{90}Y

Emerging isotopes → Small innovative suppliers

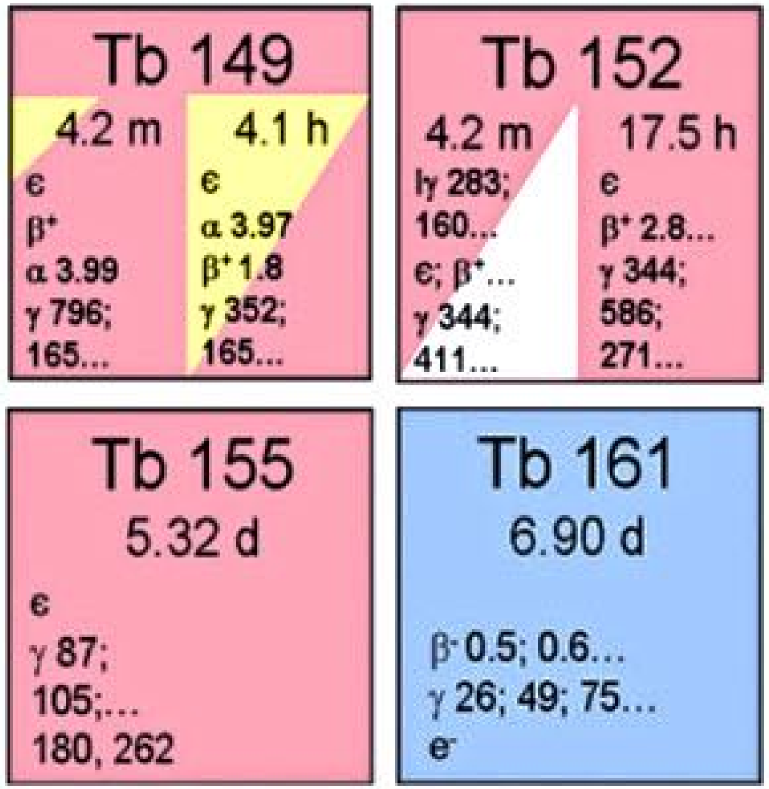
^{68}Ga, ^{82}Rb, ^{89}Zr, ^{177}Lu, ^{188}Re

R&D isotopes → Research labs

^{44,47}Sc, ^{64,67}Cu, ^{134}Ce, ^{140}Nd, $^{149,\ 152,\ 155,\ 161}$Tb, ^{166}Ho, ^{195m}Pt, ^{211}At, $^{212,\ 213}$Bi, ^{223}Ra, ^{225}Ac,…

(Courtesy Ulli Koester)

Theranostics



H2020 PRISMAP: The European medical isotope programme (Arronax, CEA, CERN, CHUV, DTU, ESS, GANIL, GSI, ILL, INFN, IST-ID, JRC, KU Leuven, LU, MedAustron, MUI, NCBJ, NPL, PSI, SCIPROM, SCK-CEN, TUM, UIO)

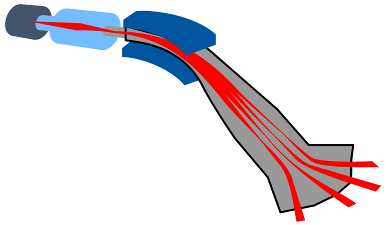
CERN: from ISOLDE to MEDICIS

Non-conventional isotopes collected by mass separation for new medical applications

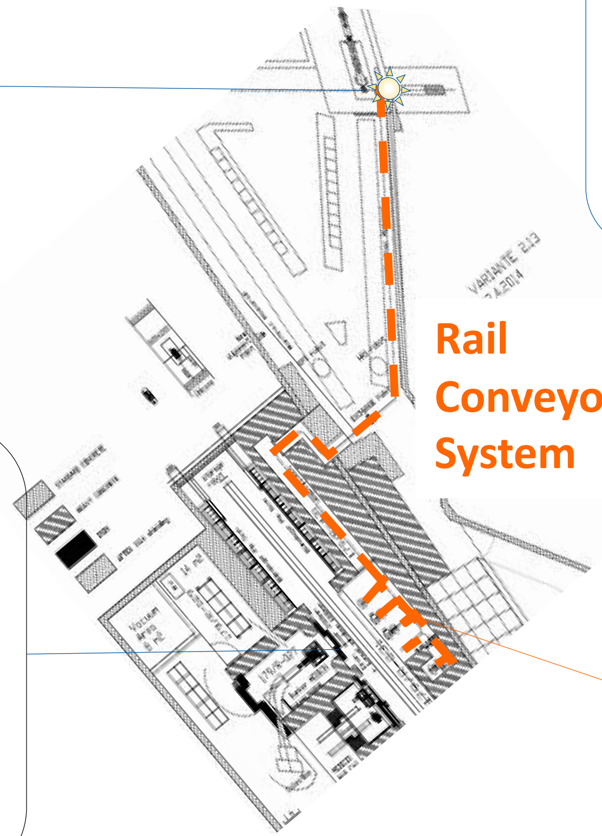
ISOLDE has been running for more than 50 years

Protons on ISOLDE target

MEDICIS Laboratory

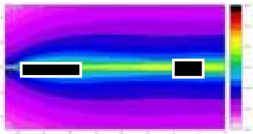


Isotope separation on-line (ISOL)



Rail Conveyor System

MEDICIS Target Irradiation



CERN: from ISOLDE to MEDICIS

Year	Irradiation modes	Medical isotopes	Collected activity (MBq)
2018	CERN PSB & external irradiations	C-11, Tb-149, Tb-152, Tb-155, Tm-165, Er-169	235
2019	External irradiations	Tb-155, Er-169, Yb-175, Pt-195m	870
2020	External irradiations	Sm-153, Tb-155, Tm-167, Ac-225	540

MEDICIS run during LS2: operating with sources irradiated outside CERN.

Sources provided by MEDICIS collaborating institutes.

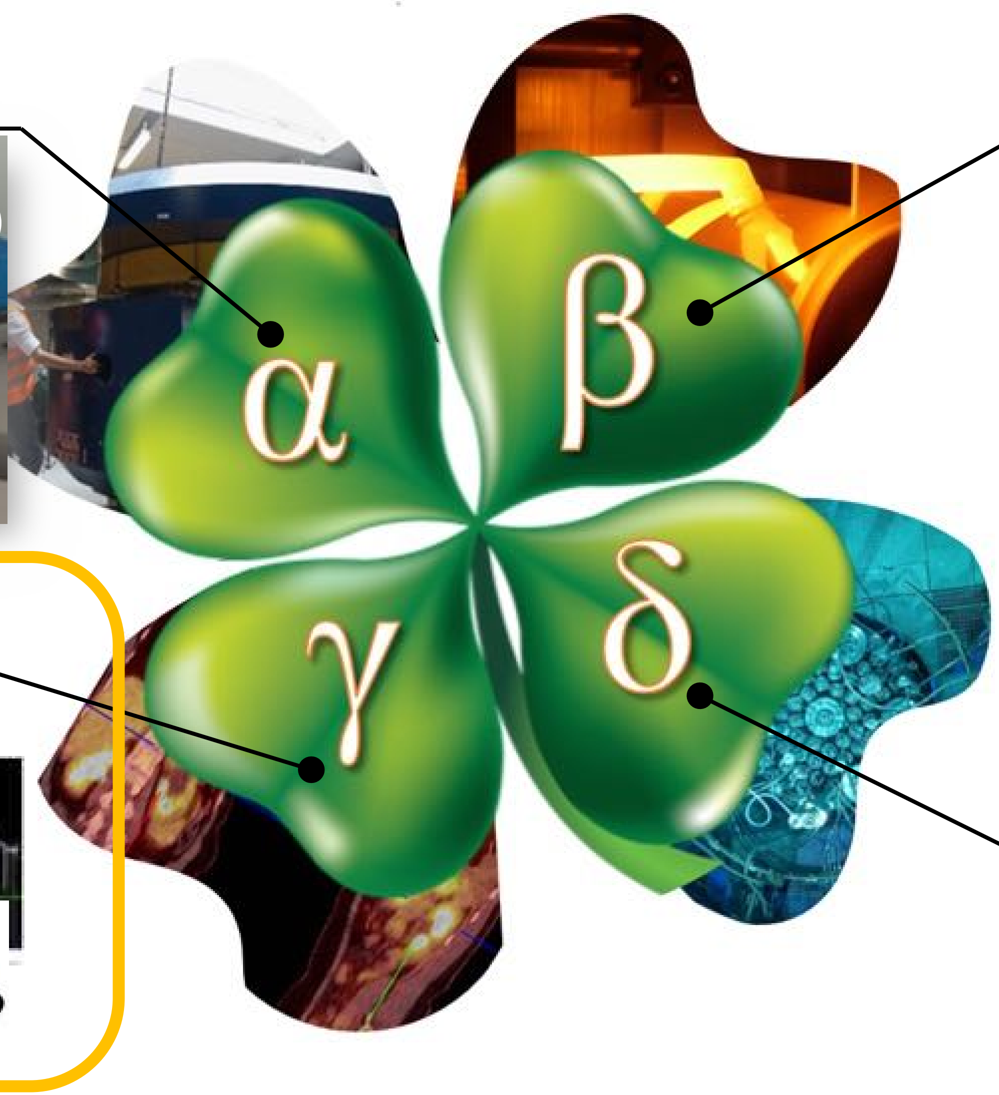
Mass separation at CERN MEDICIS when needed.

Purification in collaborating institutes by radiochemistry.

SPES - Selective Production of Exotic (nuclear) Species @ LNL

SPES-α

production and delivery to the target of Cyclotron proton beams)

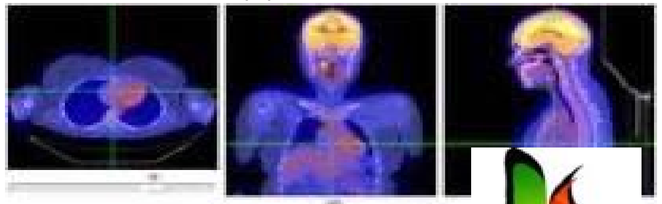


SPES-β

ISOL facility and the acceleration of neutron-rich unstable nuclei

SPES-γ

Radioisotopes for medical applications



ISOLPHARM & LARAMED

SPES-δ

Neutron source for applied physics and industry

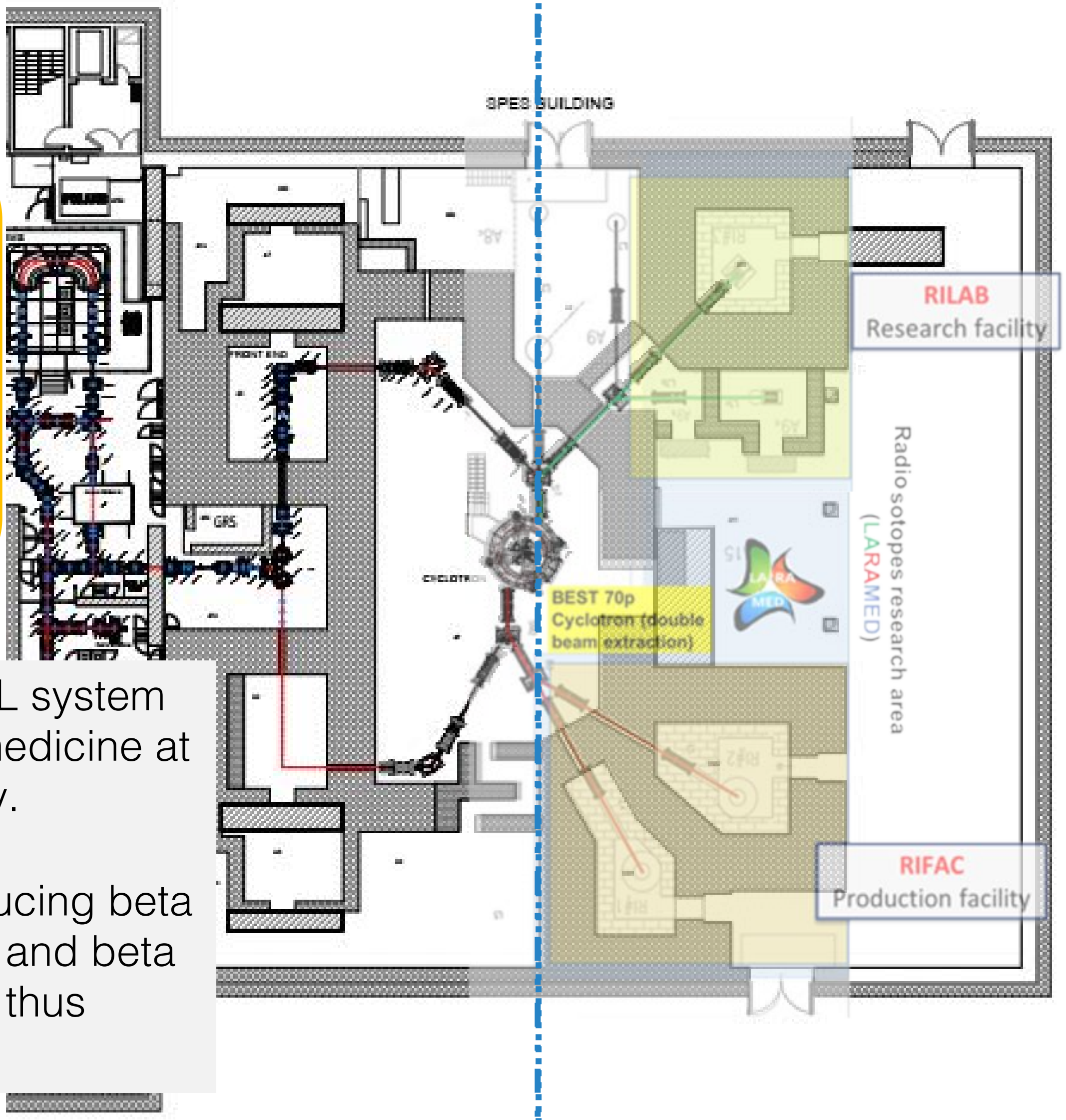
SPES-γ: innovative radioisotopes for medical applications

Production of radiosiotopes for medical applications via **ISOL technique**

ISOLPHARM
SPES exotic beams for medicine

Focused on the use of the ISOL system to produce radioisotopes for medicine at high specific activity and purity.

INFN patent «Method for producing beta emitting radiopharmaceuticals and beta emitting radiopharmaceuticals thus obtained»



Production of radiosiotopes for medical applications via **direct activation**

LAboratory of Radionuclides for MEDicine

molecules MDPI

Letter

LARAMED: A Laboratory for Radioisotopes of Medical Interest

Juan Esposito [1], Diego Bettoni [1,2], Alessandra Boschi [3], Michele Calderolla [1], Sara Cisternino [1], Giovanni Fiorentini [2], Giorgio Keppel [1], Petra Martini [1,3,*], Mario Maggiore [1], Liliana Mou [1], Micòl Pasquali [1], Lorenzo Pranovi [1], Gaia Pupillo [1], Carlos Rossi Alvarez [1], Lucia Sarchiapone [1], Gabriele Sciacca [1], Hanna Skliarova [1], Paolo Favaron [1], Augusto Lombardi [1], Piergiorgio Antonini [1] and Adriano Duatti [1,4]

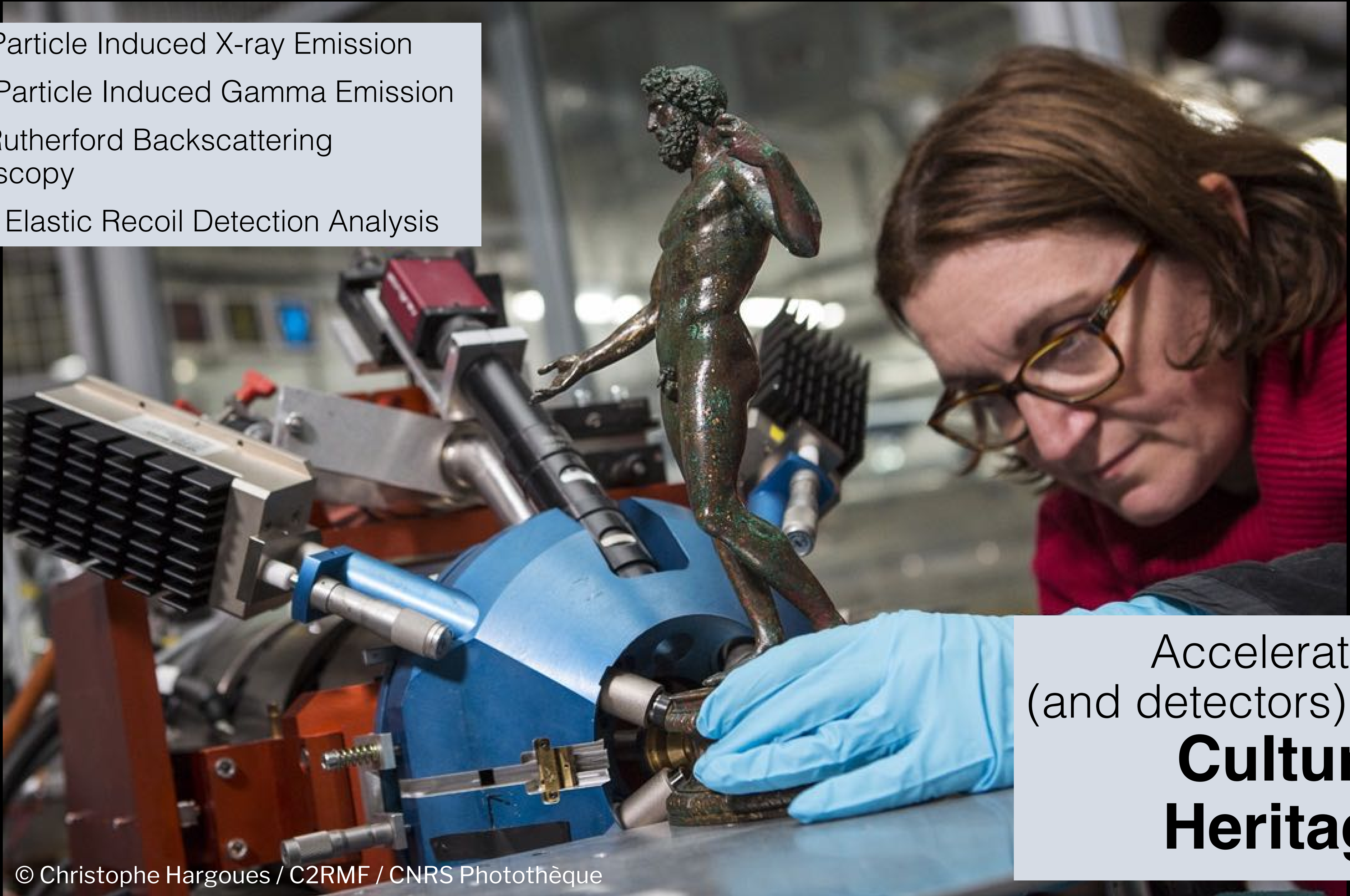
[*] Esposito J et al., Molecules **2019**, 24, 20; doi:10.3390/molecules24010020

PIXE = Particle Induced X-ray Emission

PIGE = Particle Induced Gamma Emission

RBS = Rutherford Backscattering Spectroscopy

ERDA = Elastic Recoil Detection Analysis



Accelerators
(and detectors) for
Cultural Heritage

New AGLAÉ – Accélérateur Grand Louvre d'Analyse Élémentaire


Yann Caradec, CC BY-NC-SA 2.0


Jean-Pierre Dalbéra [CC BY 2.0], wikimedia commons


CHRISTOPHE HARGOUES / C2RMF / AGLAE / CNRS PHOTOTHÈQUE

CENTRE DE RECHERCHE ET DE RESTAURATION DES MUSÉES DE FRANCE

cnrs

MACHINA

Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis

Photo: INFN

Construction of a compact, transportable accelerator

INFN

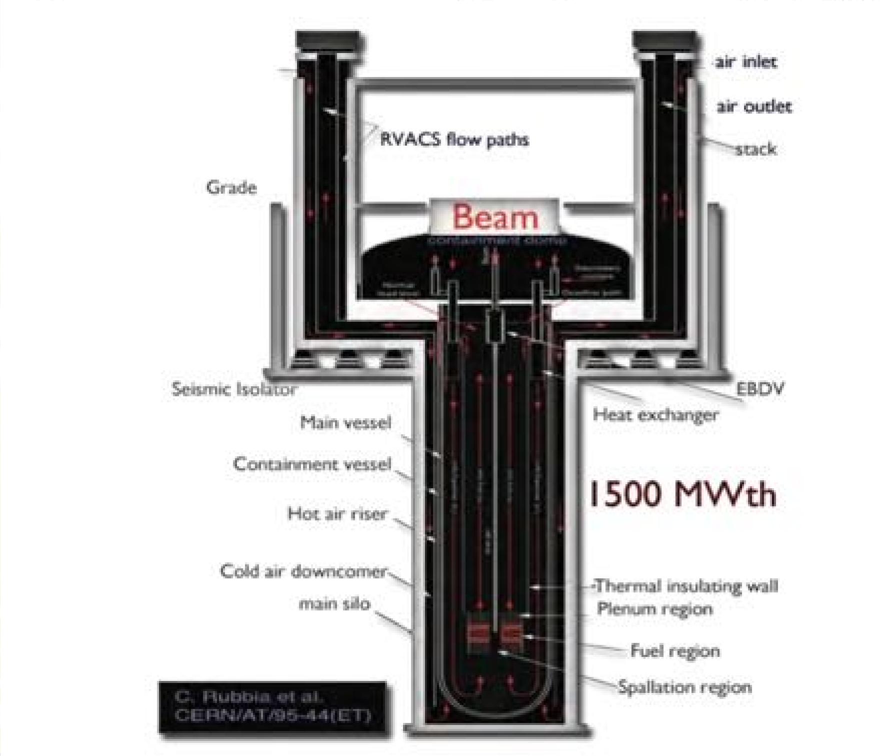
CERN

Environmental applications

Carlo Rubbia’s energy amplifier concept.

« Cleaner and inexhaustible nuclear energy production driven by a particle beam accelerator »
CERN/AT/93~47 (ET)
https://cds.cern.ch/record/256520/files/at-93-047.pdf

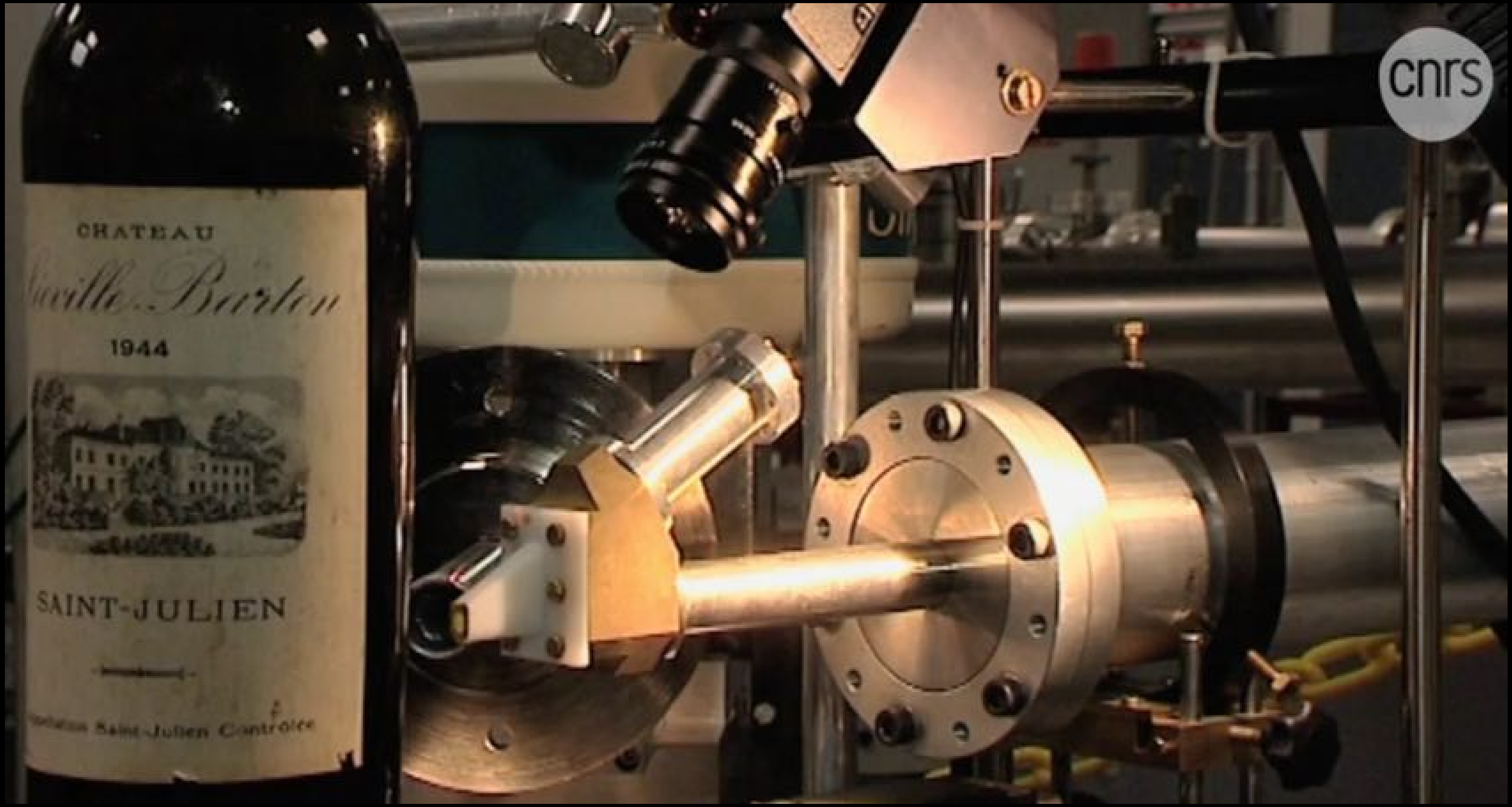
Figure 1. Carlo Rubbia's energy amplifier concept [1] [2]



(Not really HEP!)
A cruise ship emits as much sulphur oxides as 1 million cars!
So far, technical solutions exist to reduce SOx or NOx, but there is no economically viable solution for both.

Hybrid Exhaust Gas Cleaning Retrofit Technology for International Shipping (HERTIS)
150 kV electron accelerator to break the high order molecules that are then cleaned by a water jet (scrubber).

In vitrum veritas



https://images.cnrs.fr/video/2057

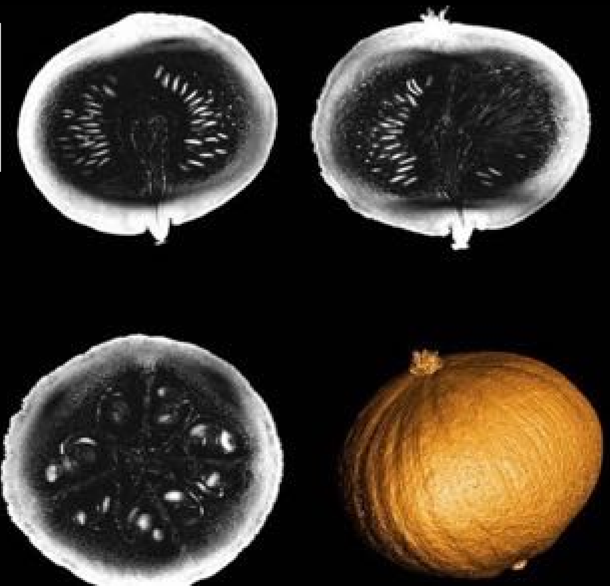
The ISEULT whole body 11.7 T MRI magnet

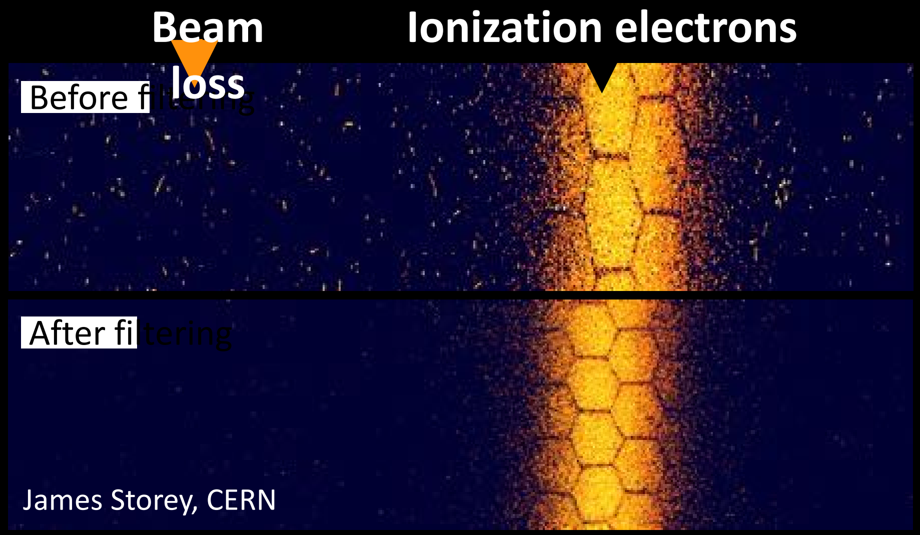
NEUROSPIN: a unique concept in neuroscience research

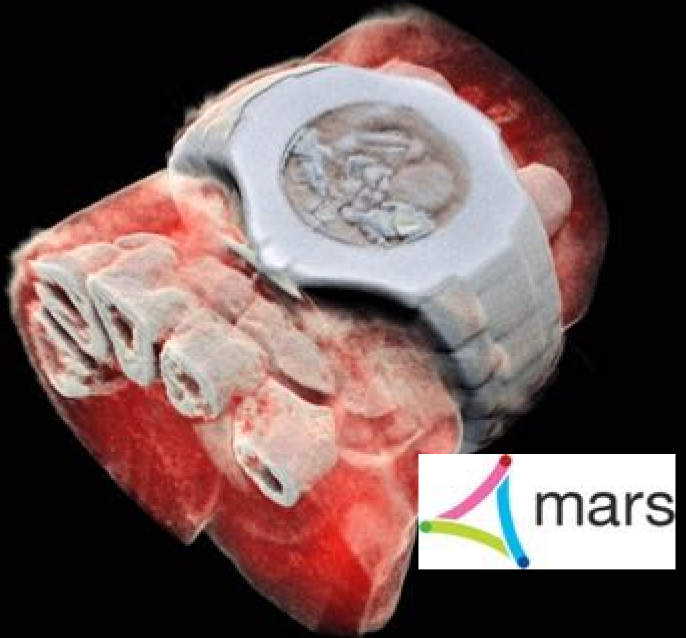
The ISEULT magnet -
a French-German initiative

Full field of 11.72 teslas achieved on July 18, 2019

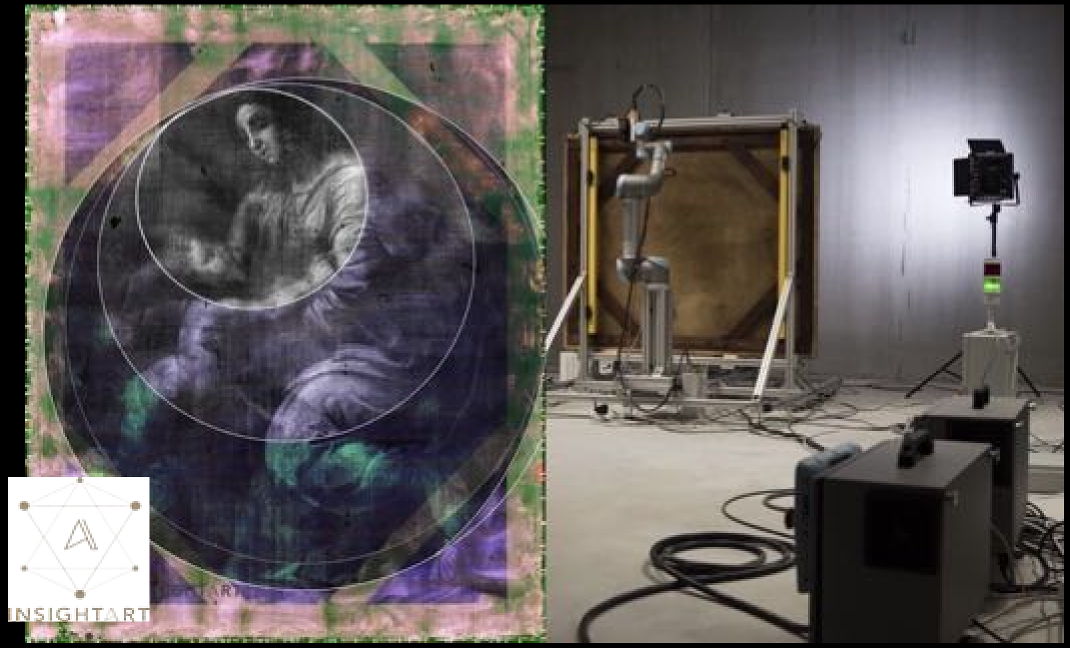
First images released Oct. 7, 2021







medipix
collaboration



20th anniversary symposium on Medipix and Timepix https://indico.cern.ch/event/782801/timetable/

A SIMULATION TOOLKIT

Space applications

European Space Agency

- Geant4 Space Users' Home Page
- ESA Project Support
- XMM-Newton Radiation Environment.
- Space Environment Information System (SPENVIS)
- Dose Estimation by Simulation of the ISS Radiation Environment (DESIRE)
- Physics Models for Biological Effects of Radiation and Shielding
- Geant4 Radiation Analysis for Space (GRAS)
- MUlti-LAyered Shielding SImulation Software (MULASSIS)

GLAST

- Gamma Ray Large Area Space Telescope

MEGAlib

- Medium Energy Gamma-ray Astronomy library

Medical applications

G4DNA
Geant4-DNA project

G4MED (in Japanese)
Geant4 Medical Physics in Japan

G4NAMU
Geant4 North American Medical User Organization

GAMOS
Geant4-based Architecture for Medicine-Oriented Simulations

GATE
Geant4 Application for Tomographic Emission

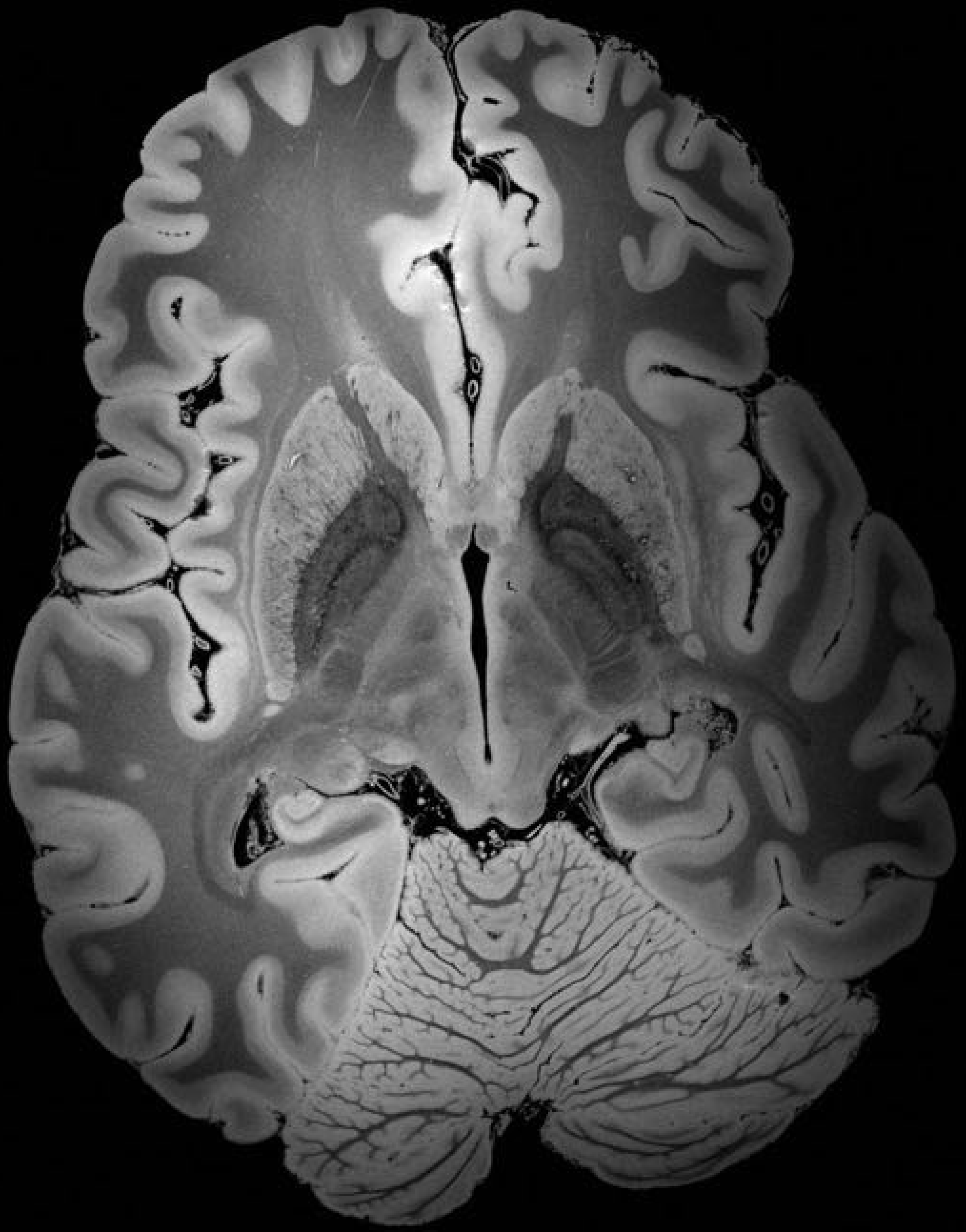
GHOST
Geant4 Human Oncology Simulation Tool

TOPAS
Geant4 Monte Carlo Platform for Medical Applications

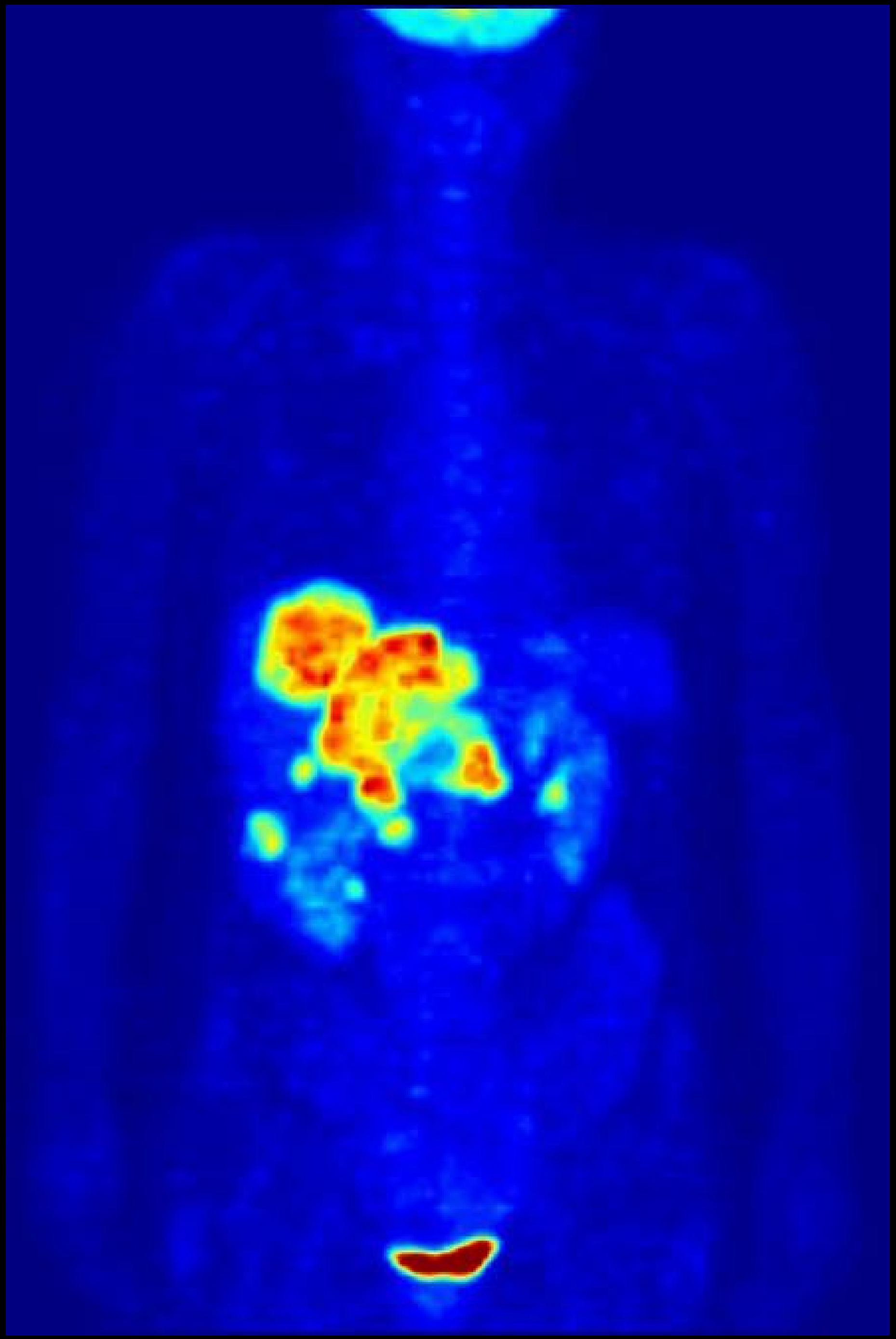
+ industrial applications

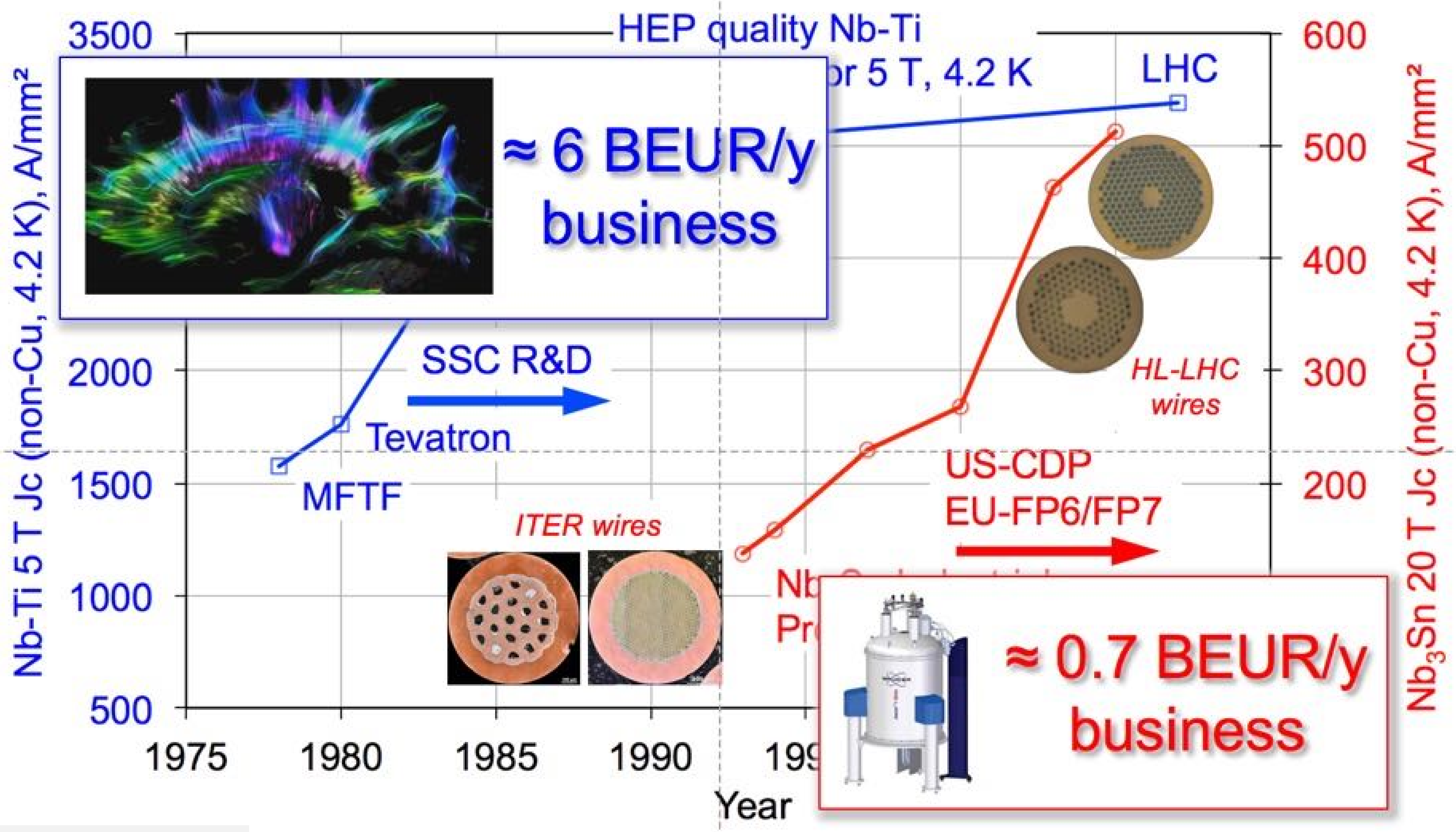
Notably, non-destructive testing

A long and winding road…



BRIAN L. EDLOW, M.D. OF MASSACHUSETTS GENERAL HOSPITAL

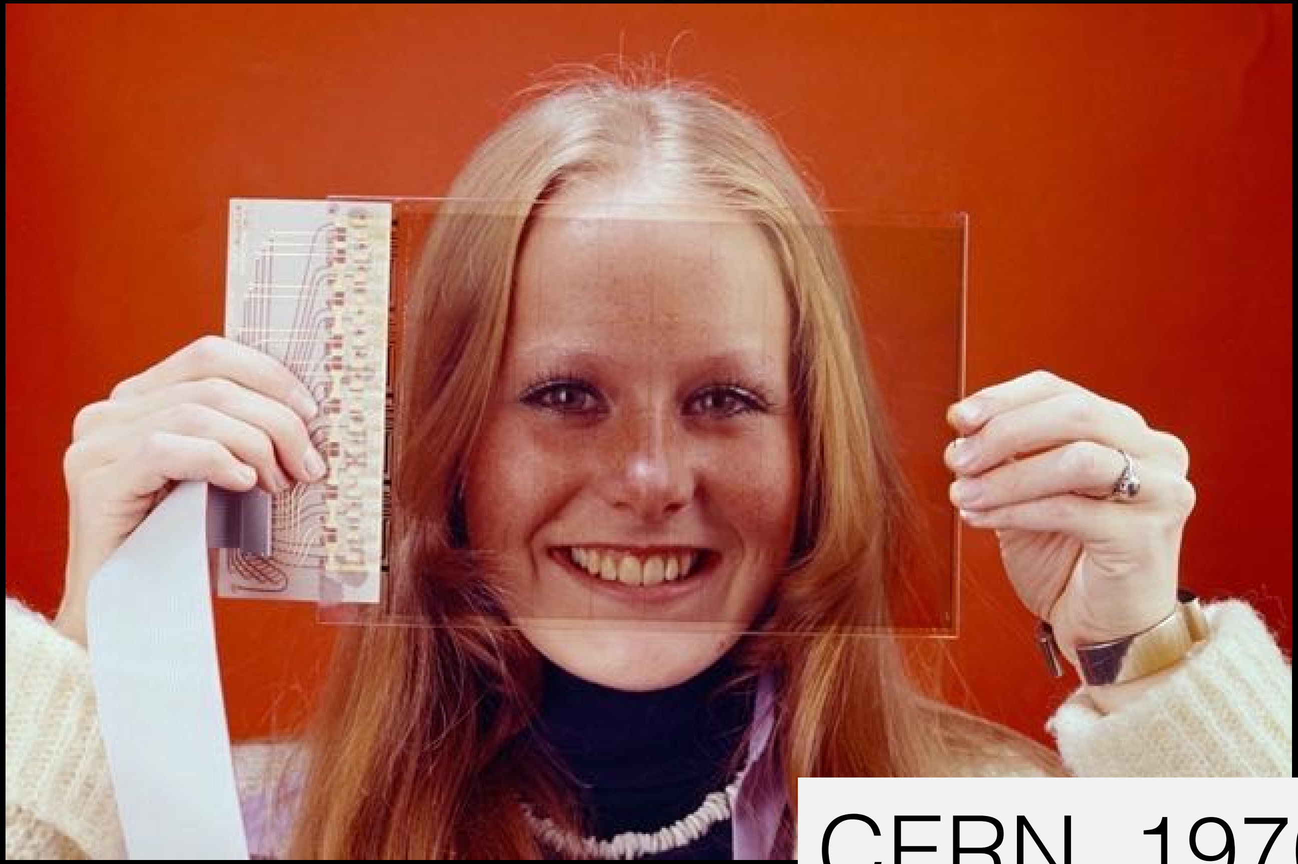




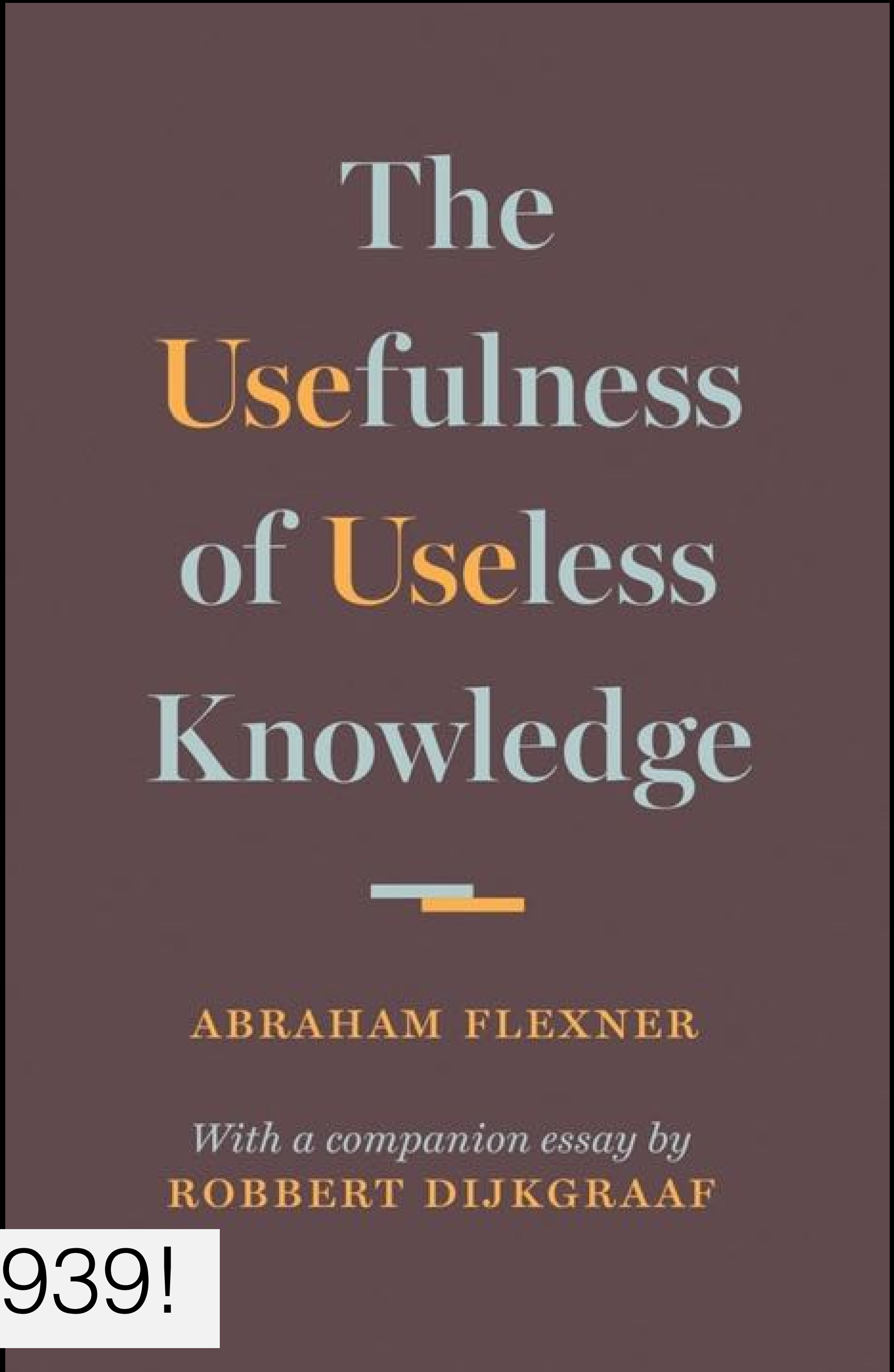
Courtesy Luca Bottura

On the unreasonable request of high J_C

How do we MAXIMISE IMPACT?



CERN, 1970s



1939!

In the end, utility resulted, but it was never a criterion to which his (*Faraday's, ndr*) ceaseless experimentation could be subjected.

I am not for a moment suggesting that everything that goes on in laboratories will ultimately turn to some unexpected practical use or that an ultimate practical use is its actual justification.

THANK YOU for your attention

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π^- beam therapy

1935 Yukawa theory on pi meson

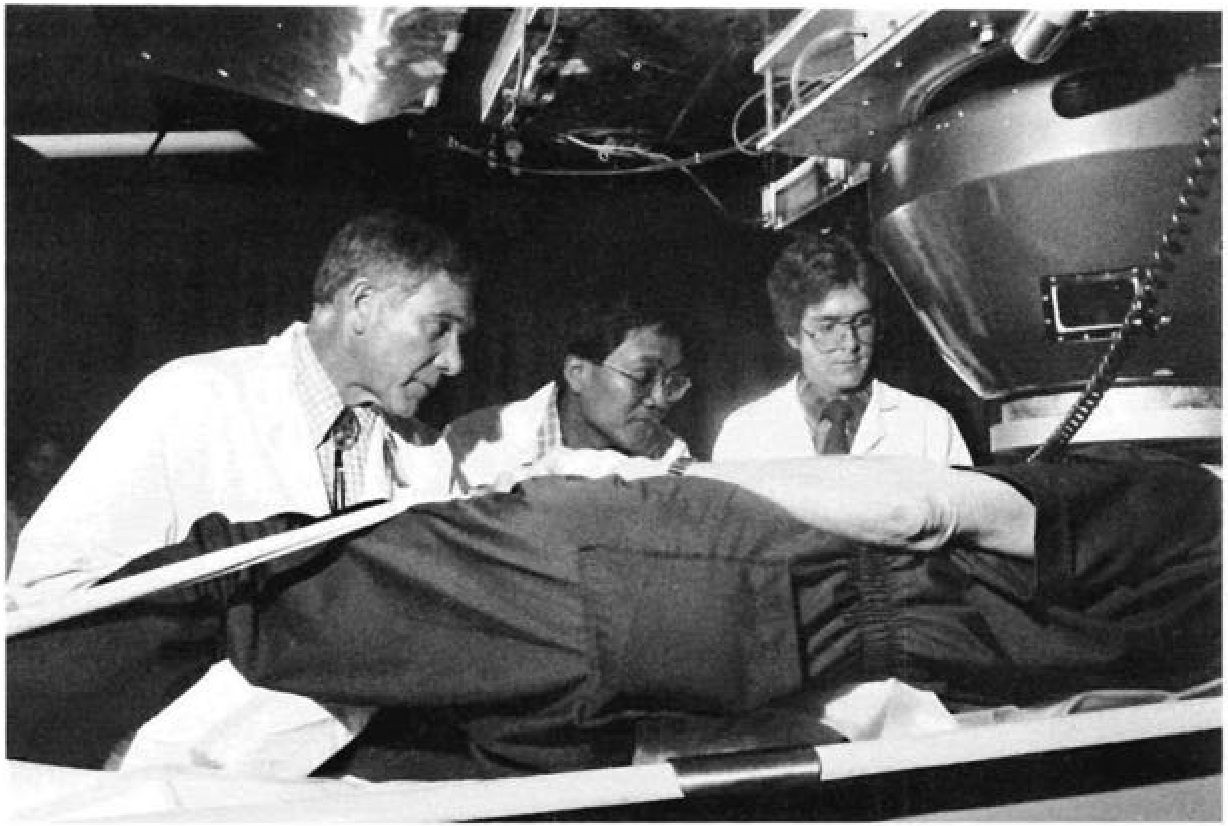
1947 Discovery of pions

1951 Possibility of using negative pions for cancer therapy (Tobias and Richman)

1961 Clinical use of π^- advocated (Fowler and Perkins, Nature 1961)

'70-'80s Clinical trials of negative pions at LAMPF, TRIUMF, PSI and Stanford

William T. Chu
EO Lawrence Berkeley National Laboratory
PTCOG From 1985 to Present and Future



In a pilot experimental program at LAMPF's Biomedical Facility, about 250 patients were treated with negative pions for a variety of advanced deep-seated tumors. Compared to conventional x-ray therapy, pion therapy is expected to provide improved dose localization and biological effectiveness. Shown positioning a patient under the pion radiotherapy beam are (left to right) Dr. Morton Kligerman, former Director of the University of New Mexico's Cancer Research and Treatment Center, a visiting radiotherapist from Japan, and Dr. Steven Bush, formerly of the University of New Mexico. The hardware at the upper right includes a beam collimator, a dose monitor, and a device for changing the penetration depth of the pions.

LAMPF: a dream and a gamble